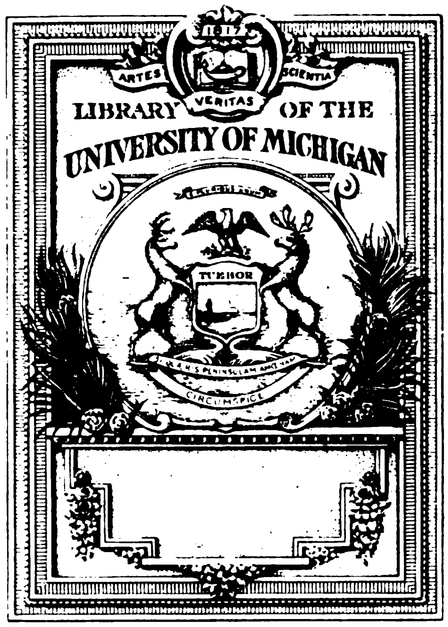
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GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER 61

GLACIATION

OF THE

UINTA AND WASATCH MOUNTAINS

BY

WALLACE W. ATWOOD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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GLACIATION OF THE UINTA MOUNTAINS.

LOCATION AND EXTENT OF AREA.

The Uinta Mountains are located in the northeastern portion of Utah and consist of a single range of peaks extending in a general east-west direction. If the crest line of this range were continued westward it would cross the Wasatch Range nearly at a right angle and reach the great Bonneville basin a few miles south of Salt Lake City. These two mountain ranges therefore stand nearly at right angles to each other, and yet are separated by a distance of not more than 10 miles. (See fig. 1.)

The portion of the Uinta Mountains examined for evidence of ancient glaciation extends from the west end of the range, in longitude 111° 15′ E. to longitude 109° 40′. Farther east the range descends in elevation and the topographic map of this portion of the mountains exhibits no indications of ice action. The areal extent of the region studied is somewhat over 2,500 square miles. It includes the east-central portion of the Coalville (Utah-Wyo.) quadrangle, all of the Hayden Peak and Gilbert Peak (Utah-Wyo.) quadrangles, the greater portion of the Marsh Peak (Utah-Wyo.) quadrangle, and some adjoining territory north and south of these quadrangles.

TOPOGRAPHIC RELATIONS.

The Uinta Mountains rise somewhat gradually above the plateau countries to the north and south and reach their maximum elevation in the central portion of the range, where the highest peaks stand 13,400 to 13,525 feet above sea level. The maximum elevation of the mountains above the surrounding country is about 7,000 feet. From the high central portion of the range the crest line descends gently both to the east and to the west. At the west end the descent is rather abrupt, but toward the east the range becomes irregular in form and ill defined, so that it is not easily distinguished from the bordering plateaus and mesas, and thus gradually fades out.

The range is widest in its central portion, where it measures, in a north-south line, fully 35 miles. To the east and west of the central portion the decrease in width is very noticeable. To the west the narrowing is symmetrical, and the terminus of the range is lobate in form, being sharply defined at the north and south by the valleys of Weber and Provo rivers, respectively. To the east the narrowing is not so pronounced nor so symmetrical, and this feature of the range, together with its general flattening out in this direction, accounts in part for its less conspicuous eastern terminus. The length of the range, as defined by the Fortieth Parallel Survey, is about 150 miles.[a] This report is concerned with the western 85 miles of the mountains.

[a] King, Clarence, U. S. Geol. Explor. 40th Par., vol 2, p. 194.

GEOLOGICAL STRUCTURE AND FORMATIONS.

The general geology of the Uinta Mountains was published in 1877 and 1878 in the reports of the United States Geological Explorations of the Fortieth Parallel. Other descriptions of geological features of the range may be found in the following publications:

HAYDEN, F. V., U. S. Geol. and Geog. Survey Terr., 1871 (1872), p. 41 et seq.

POWELL, J. W., Report on the geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 1876.

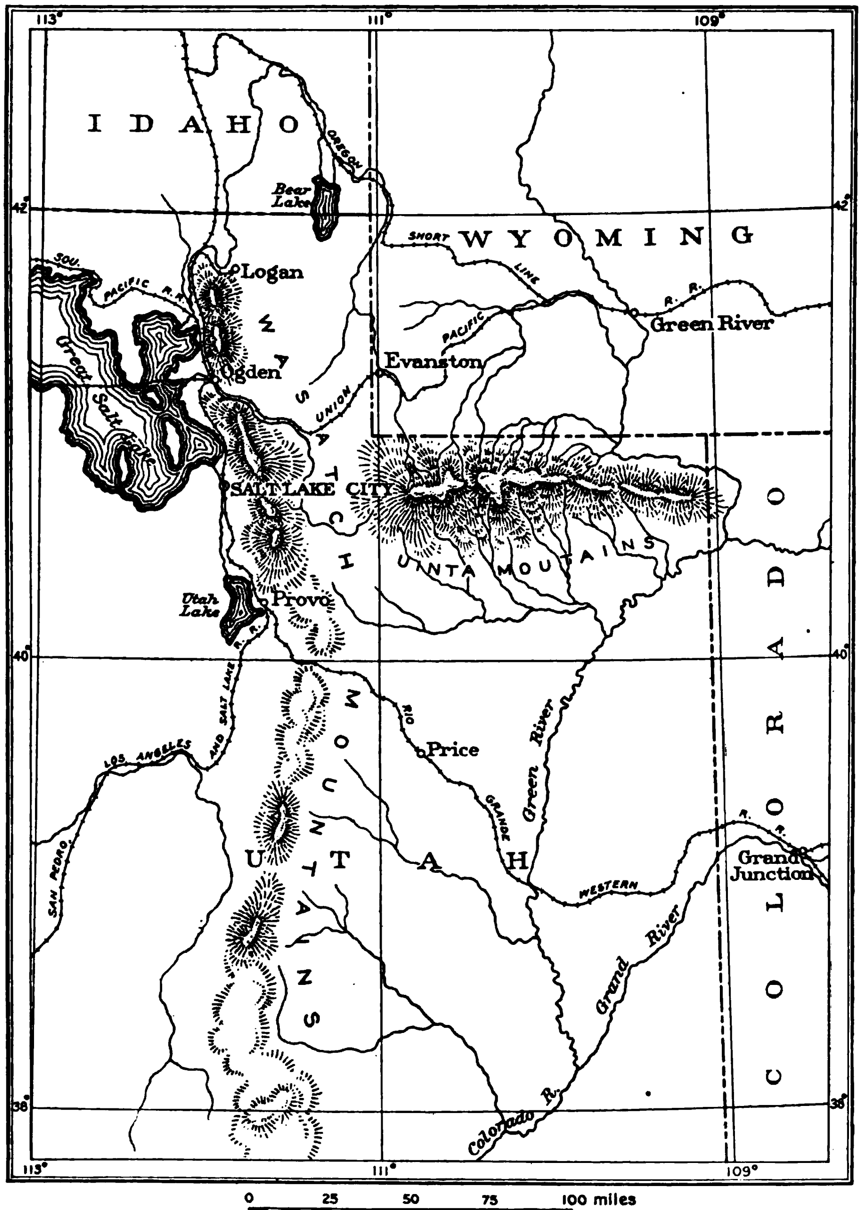


FIG. 1.—General map showing location of Wasatch and Uinta mountains, the main drainage lines of the region, and the larger outfitting points.

WHITE, CHARLES A., On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming (under heading "The Uinta fold): Ninth Ann. Rept. U. S. Geol. Survey, pp. 692–697.

VAN HISE, C. R., Principles of North American pre-Cambrian geology (under heading "The Uinta Mountains"): Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, pp. 820–821.

Van Hise, C. R., Correlation papers—Archean and Algonkian; A review of the present state of knowledge of the pre-Cambrian rocks of North America (under heading "Literature of the Uinta Mountains"): Bull. U. S. Geol. Survey No. 86, pp. 286–289; also (under heading "The Uinta Mountains") p. 505.

Eldridge, George H., The uintaite deposits of Utah (under heading "Geology of the Uinta Basin"): Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, pp. 920–946.

Boutwell, J. M., Iron ores in the Uinta Mountains: Bull. U. S. Geol. Survey No. 225, pp. 221–228.

Berkey, C. P., Mineral resources of the Uinta Mountains: Eng. and Min. Jour., vol. 77, 1904, p. 841.

Weeks, F. B., Stratigraphy and structure of the Uinta Range: Bull. Geol. Soc. America, vol. 18, 1907, pp. 427–448.

In this report a brief summary of the general geology[a] will be presented, with special reference to those features that have influenced glaciation. Pl. I is a historical geology map of the western portion of the Uinta Mountains and the surrounding country, including an area somewhat larger than that here considered.

The central portion of the range is a broad, plateau-like crest of an immense anticline, now deeply dissected. The axis of the fold is not in the center of the range, but nearer its northern margin. It follows approximately the northern face of the higher peaks. For 150 miles from east to west and for 10 or 15 miles from north to south the beds of this great plateau lie nearly flat, nowhere departing more than 5° or 6° from this horizontal position, except in slight local undulations. At the margins of the plateau, however, the arch gives way abruptly and the beds decline at angles of over 45°, and at places reach a vertical position. In the zones of highly inclined strata minor folds and faults are found, although these marginal structures are at places obscured by the heavy forest and by Tertiary beds and glacial moraines. The principal displacement is along the northern side of the arch.

In the areas immediately north and south of the range the Tertiary formations are approximately horizontal, lapping over the lower slopes of the mountains. The Quaternary formations, as mapped by the Fortieth Parallel Survey, consist of valley alluvium lying at some distance from the mountains. At the west end of the range a trachytic flow, together with recent alluvium in the Kamas Prairie, obscure the structural conditions in the region between the Uinta and Wasatch ranges. The eastern end of the fold was not visited and is not included within the area considered in this report.

The oldest formation exposed in the region studied is the pre-Cambrian quartzite. This formation constitutes the main body of the range (see Pl. I) and is exposed throughout the central plateau portion. To the east, in the area under consideration in this report, the pre-Cambrian quartzite group is represented chiefly by dark-red sandstones, which become more and more compact toward the west, until, in the western half of the range, dark purplish-red quartzites predominate. Interstratified with the massive beds of sandstones and quartzite are layers of argillaceous shales and coarse grits, the latter containing rounded grains of quartz, at places large enough to form fine conglomerates. In the coarser beds there is at many places a considerable admixture of broken feldspar crystals. The argillaceous beds are for the most part of greenish or brownish color, and in the west-central portion of the region aggregate approximately 100 feet in thickness.

The Cambrian shales border the range as nearly continuous belts on both the north and south slopes (see Pl. I), and stand at highly inclined angles on the flanks of the great fold. The Ordovician quartzite rests conformably upon the Cambrian shales on the south side of the range but has not been recognized on the north side.

Farther out from the crest of the range and higher in the geological column lies the Mississippian series, consisting of white and gray to greenish quartzites. The Pennsylvanian rests conformably upon the Mississippian. The "Permo-Carboniferous" beds appear as narrow, discontinuous belts in the foothills of the range. (See Pl. I.)

[a] Based on paper by F. B. Weeks, Bull. Geol. Soc. America, vol. 18, 1907, pp. 427–448.

Conformably upon the "Permo-Carboniferous" strata lie the Triassic beds, consisting of white, buff, and reddish sandstones, at places brick-red in color, intercalated with clay and shaly material. They are exposed at only a few points, being buried by the overlapping Tertiary beds and glacial moraines. In upper Weber Canyon 700 to 800 feet of Triassic beds are exposed, while on the East Fork of the Du Chesne 1,900 feet of that formation are shown.

The Jurassic formations, in conformable relations with the Triassic, occupy their appropriate place on the flanks of the great anticlinal fold. They consist of 600 to 800 feet of limestone, sandstones, and shales, but they are largely buried, outcropping in but six of the canyons visited.

The Cretaceous beds, conformable with the Jurassic, also rest at highly inclined angles on either side of the fold. They consist of over 10,000 feet of conglomerates, sandstones, and shales, but are largely buried by Tertiary formations.

Near the close of Cretaceous time a powerful orographic movement disturbed the formations in this region. The great Uinta anticline began to rise. As the elevation increased the forces of degradation became more powerful, and in the long period of erosion that ensued these forces greatly reduced the level of the range. Thousands of feet of rock strata were removed and deposited over the lower countries to the north and south. On the flanks of the mountains broad areas of inclined strata were truncated, and probably the entire range was brought to the peneplain stage.

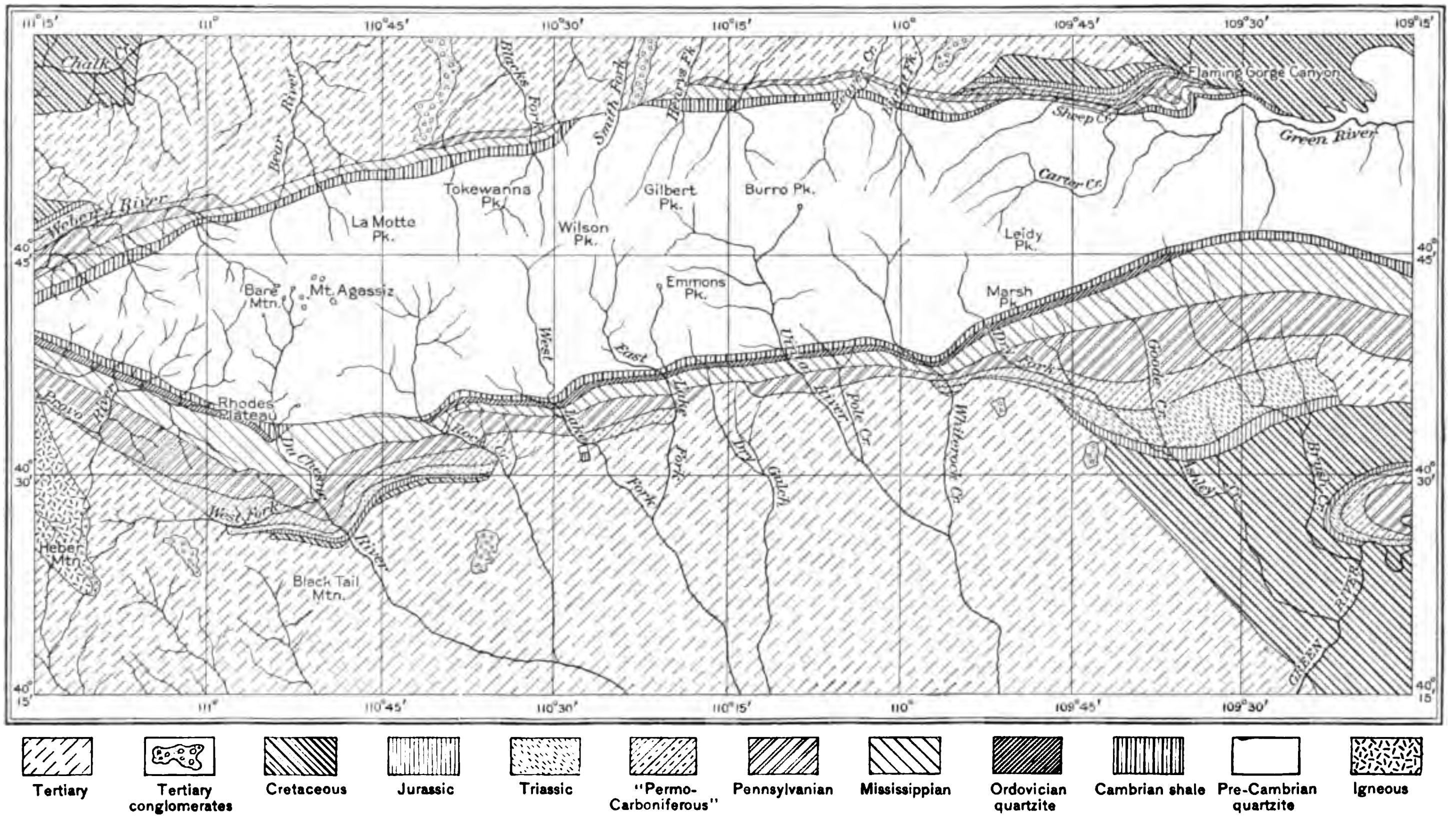
Upon the truncated strata rest the Tertiary formations, consisting of sandstones, shales, and conglomerates. These layers are of much looser texture than the Paleozoic and Mesozoic beds, and at places the materials are not cemented. The Tertiary conglomerate, the uppermost Tertiary formation in the region, is a coarse conglomerate, at places truly structureless, but in some exposures distinctly stratified. Its distribution in the region is wider than that indicated on Pl. I. The material in this formation grades from fine sands to bowlders 8 feet in diameter. The larger bowlders are composed of quartzite. In composition the Tertiary conglomerate is identical with much of the glacial drift in the region. When deeply eroded or modified by slumping this material is easily mistaken for glacial drift, and it has added considerable difficulty to the glacial studies, especially in the heavily wooded portions. After the deposition of the Tertiary conglomerate there was another long period of erosion, during which the deep canyons through which the glaciers moved were excavated.

All of the formations mentioned above have contributed, though in very different amounts, to the glacial drift in this region. The broad expanse of pre-Cambrian quartzite in the central portion of the range accounts for the predominance of material from that formation in the glacial drift, a predominance so marked that the glacial drift of the Uinta Mountains, except that of one canyon, consists principally of quartzite. Certain glaciers that did not extend beyond the outcrop of the pre-Cambrian quartzite carried nothing but débris from that formation. The glaciers that moved out beyond the great quartzite layers and crossed the upturned beds on the flanks of the range gathered some limestone, some sandstone, and a little shale. Those glaciers that reached the Tertiary formations gathered large quantities of conglomerate.

Some of the Quaternary alluvium mapped by the Fortieth Parallel Survey contains wash from the glaciers, and will be considered later in the report.

PHYSIOGRAPHIC FEATURES.

The physiographic features of the region show a close relationship to the geologic structure and formations. The sculpturing of the softer horizontal strata north and south of the mountain range has given rise to broad, open valleys of softened contour. At places a harder layer among the Tertiary formations has acted as a preserving cap to underlying softer beds, and in the process of degradation these protected areas have been left as mesas or buttes that



GEOLOGIC MAP OF WESTERN PORTION OF THE UINTA MOUNTAINS.

After F. B. Weeks.

rise somewhat above the general level of the country about them. A portion of the bordering land, in Wyoming, north of the Gilbert Peak quadrangle, has a typical "badlands" topography.

The upturned layers on the flanks of the range now stand out at places as a series of hogback ridges separated by parallel, troughlike valleys. The harder layers constitute the ridges, while the softer beds mark the location of the parallel valleys. These features are best shown at the north margin of the Gilbert Peak quadrangle. Where the main streams of the range cross the upturned harder strata their valleys are constricted, and such places are popularly known as gateways. (See Pl. II, *B*.)

All the great canyons of the Uintas head near the crest of the range and descend approximately to the north or to the south. Since the axis of the range is nearer the north than the south margin, the canyons on the north slope are shorter than those on the south slope. All of the larger canyons have the characteristic U-shaped form due to glaciation. Their upper portions have been well cleaned out by the ice, but their middle and lower portions contain heavy morainic deposits.

The streams in these canyons flow with the dip of the strata, and as they have lowered their beds, receiving considerable help from the glaciers, they have come to flow across the truncated edges of the layers in the great fold. As these layers are not of equal hardness, series of asymmetrical ridges have been developed in certain canyons at right angles to the general courses of the streams. This is notably true of the North Fork of Provo and of Henrys Fork, where the streams dash against one after another of the upturned layers, cutting narrow notches through them, and then flowing for a time on the bedding surface, down dip, reaching other upturned edges, and so on. In these canyons glaciation has done much to reduce the cross ridges, and the absence or inconspicuousness of such forms in many of the canyons is probably due to powerful erosion by the ice.

Most of the streams of the south slope, notably the Du Chesne, Rock Creek, the East and West forks of Lake Fork, the Uinta, and the Whiterock, flow in sharp inner canyons. These canyons extend from points within a few miles of the crest of the range southward for 6 to 10 miles. They begin and end gradually. At the downstream end the channel is but slightly intrenched; farther up it becomes more and more deeply intrenched, until the stream flows in a narrow rock gorge 40, 50, or even 90 feet below the general level of the valley bottom. Still farther upstream the depth of the inner rock gorge decreases until, near the lower margin of the catchment basin at the head of the stream, the channel is not noticeably intrenched. Upstream from the inner gorges the canyons broaden out and have wide, flat-bottomed basins, bordered by steep walls, at places precipitous. Downstream from the inner gorges the main canyons, as far as they have been glaciated, have broad, open, U-shaped forms. Beyond the outermost moraines, in the lowlands, the valleys do not have the canyon form, but are margined by low, gently sloping bluffs. These lower portions of the valleys are at some places bordered by terraces.

The basins at the heads of the canyons on the north slope vary in area from 1 to 12 square miles, but many of those on the south slope include 20 to 30 square miles. This difference, to be discussed later, is consistent with the general structure of the range, for the basins on the north slope are in the zone of the more inclined beds, while those on the south slope have been developed in the broad plateau crest, where the beds are nearly horizontal and where the conditions were most favorable for plucking and sapping and for the development of broad, flat-bottomed cirques.

The higher central portion of the great fold is now sculptured into a series of peaks, many of which rise 12,000 to 13,000 feet above sea level, and into narrow spurs which project into the basin region and divide it into a large number of cirques. (See Pl. II, *A*.)

In the western part of the range, in the hard quartzite, sharp, castellated forms occur, similar to those in the Grand Canyon of the Colorado. The nearly horizontal beds are sufficiently varied in hardness to give rise to minor cliffs and benches on the peaks, and

the colors, though less brilliant than those of the Grand Canyon region, are nevertheless at places strikingly beautiful.

The scenery of this elevated region is singularly wild and picturesque, both in form and coloring. In the higher portions of the range where the forest growth is extremely scanty the effect is that of desolate grandeur; but in the lower basin-like valleys, which support a heavy growth of coniferous trees, the view of one of these mountain lakes, with its deep-green water and fringe of meadow land, set in the somber frame of pine forests, the whole inclosed by high walls of reddish purple rock whose bedding gives almost the appearance of a pile of Cyclopean masonry, forms a picture of rare beauty.[a]

To the east, where the rock is softer, the crest line and associated peaks have a rounded, softened contour, with an abundance of talus material. (See Pl. III, *A*.) In the capacious amphitheatral basins among these lofty peaks the snows which formed the glaciers collected.

GLACIATION OF THE RANGE.

The report of the Geological Explorations of the Fortieth Parallel contains[b] a brief account of the glaciation of the Uinta Mountains, but at that time the glacial formations were not studied or mapped in detail.

Every large canyon that heads near the crest of the range, in the portion considered in this report, has been glaciated. The floors of the basins in which the ice formed are all above 9,000 feet, although not all the basins in the region above 9,000 feet have contained true glacier ice. On the flanks of the range and in the bordering country there are basins at altitudes above 10,000 feet which did not contain glaciers, for in order to become the site of a glacier a basin must not only have had the necessary elevation, but its form and location must have been favorable to the generation of ice. Many of the less favorably situated basins contained névé, and the records of névé work at several places will be reported.

Proportional to the larger catchment basins on the south slope of the range, the glaciers on that slope were larger and longer than those on the north slope. Proportional to the greater height of the range and longer canyons in the central portion of the area concerned, the glaciers in that portion were longer. The map accompanying this report (Pl. IV, in pocket) shows a general symmetry in the size and arrangement of the ancient glaciers which corresponds in a very evident way with the general physiographic form of the area. The glaciers in the central portion of the range were 20 to 27 miles long, while those to the east and west were successively shorter, until, at the extremities of the area, most of them were but 4 or 5 miles long. Near the western end of the range, about Bald Mountain and Reids Peak, the ice of the two slopes coalesced, forming a great ice cap. The lofty peaks near the crest line in this portion of the range rose as nunataks but a few hundred feet above the ice. In the greater portion of the range the divide was not covered by ice.

Evidences of at least two epochs of glaciation appear in the region. Of these two epochs the earlier was presumably the longer, for the ice of that epoch was thicker and extended farther down the canyons than the ice of the later epoch. The lower limits to which the ice descended on the north slope in the earlier and later epochs are approximately 8,000 and 8,400 feet, respectively. On the south slope the lower limits during the earlier and later epochs are approximately 7,000 and 8,000 feet, respectively. Some data have been collected which suggest a threefold division of the glacial deposits, but not sufficient to demonstrate three distinct epochs.

The records of the glaciers of the north slope will be considered first in geographic order, beginning at the west end. Afterwards the records of those of the south slope will be reported, but these will be taken up in geographic order from east to west, thus completing the circuit of the range. The basins that contained the glaciers have been numbered on the map (Pl. IV, in pocket) in the order indicated.

[a] Geol. Explor. 40th Par, vol. 2, p. 194.

[b] Geol. Explor. 40th Par., vol. 2, pp. 470-473.

A. DIVIDE EXTENDING SOUTHWARD FROM MAIN CREST LINE OF UINTA RANGE, WEST OF ROCK CREEK BASIN.

B. SINGLE GATEWAY ON NORTH SIDE OF UINTA RANGE.

East Fork of Beaver Creek, looking southwest.

GLACIAL PHENOMENA OF THE CANYONS OF THE NORTH SLOPE.[a]

SWIFTS CANYON (BASIN 1).

Swifts Canyon is tributary to Weber River valley, on the north slope of the range, near its western end. It is one of the minor canyons of the range and it contained one of the smallest independent glaciers, and presumably one of the shortest lived glaciers, which existed in the region. The records of this glacier are by no means so striking as those of the glaciers farther east, and yet the characteristic results of ice action are apparent in the canyon, and there is some evidence leading to a twofold division of the deposits.

Swifts Canyon is scarcely 5 miles long, but its catchment area, basin 1, is favorably situated on the north side of Hoyt Peak, which has an elevation of 10,248 feet. The floor of the basin has an elevation of about 9,500 feet and is bordered by high walls which favored the preservation of snows.

Two miles above its mouth this canyon assumes an open, U-shaped form, and ridges of débris lie on the lower portions of the slopes. These débris ridges are much weathered and eroded, but show unmistakable signs of glacial origin in subangular and striated material and in their moraine-like forms. They are the lateral moraines of a glacier which pushed 2½ miles down the canyon, reaching its maximum extension near the junction of the main canyon with its east fork, a tributary which heads in basin 2. The lower limit of glaciation in Swifts Canyon is at 7,300 feet. A terminal moraine was undoubtedly left at the downstream margin of the ice, but it has since been removed by stream erosion. The valley between the lateral moraines is largely filled with postglacial wash. The bowlders of these outer lateral moraines are chiefly of quartzite, although there are some of sandstone and limestone among them. The finer material of the drift consists of sand and clay.

Farther up the canyon, at an elevation of 8,400 feet, other morainic deposits, several hundred feet thick, cross the canyon as a complex of ridges, and the stream passes beneath or through them. This material is both fresher as to weathering and younger as to stream erosion than the moraines farther downstream. Above this younger moraine the stream flows at the surface, passing among the lesser drift hills which mask the floor of the canyon and continue upstream, even into the basin. About the rim of the basin considerable talus has accumulated since the ice melted. One small lake yet remains among the débris deposits in the basin. The maximum thickness of ice in the canyon was probably not at any point more than 500 feet.

The relation and condition of the moraines in this canyon indicate that the lower, outer remnants, resting on the valley slopes, belong to an earlier glacial epoch than that which gave origin to the more massive, fresher deposits upstream. The evidence of two epochs of glaciation found here would not be satisfactory were it not strengthened by analogous conditions in other canyons where two epochs are demonstrable.

EAST FORK OF SWIFTS CANYON (BASIN 2).

The east fork of Swifts Canyon (basin 2) also contained ice. This tributary heads not at the crest of the range, but nearly 2 miles down its north slope. The catchment area at its head is poorly defined and is not more than 1 square mile in extent. The floor of this catchment area is 9,000 to 9,500 feet above sea level and the bordering walls are but a few hundred feet higher. It is surprising that a glacier formed in this basin at all.

The facts that must be cited to explain the formation of ice in basin 2 are its location on the north slope, where melting was not so rapid as on the south slope, and its proximity to regions of heavy snowfall, which made it possible for it to receive considerable wind-blown snow. This is the lowest basin in the range in which true glacial ice formed and from it descended the smallest independent glacier of the region.

[a] The glacial formations of the range are represented on Pl. IV (in pocket).

The moraines, which are the chief evidence of glaciation in this valley, extend 1½ miles downstream from the upper margin of the basin, to an elevation of 7,800 feet. They are all somewhat irregular except the lateral ridges, which strongly suggest the former presence of ice. The drift is composed of bowlders of quartzite, sandstone and limestone, mingled with large quantities of sand and clay. Striæ are yet preserved on the under surfaces of many of the larger stones. Alluvial deposits associated with the ice are wanting in this valley.

The deposits can not be subdivided between different glacial epochs and it is not easy to determine the epoch to which they belong. If the ice formed here but once, the lower and less favored catchment basin would favor the interpretation that it formed during the earlier or more extensive epoch of glaciation, rather than during the later epoch. Furthermore, the degree of weathering and stream erosion shown by the drift deposits in the tributary indicate that they correspond in age with the earlier rather than with the later moraines in the main canyon. There are no lakes or ponds among the deposits, and in the basin there is everywhere sufficient soil for forest growth. Most of the basins glaciated during the later epoch contain very little loose material, and comprise broad areas of bare rock on which no large trees or plants can grow. For these several reasons the deposits in this valley have been classed with those of the earlier epoch of glaciation.

SOUTH FORK OF WEBER RIVER CANYON (BASINS 3, 4, AND 5).

The next tributary entering Weber River east of Swifts Canyon is known as South Fork, which heads near the crest of the range, in basins 3, 4, and 5, and flows northward through a canyon 7 miles long, joining the main stream. A little over 3 miles above the mouth of this tributary there are morainic ridges on the side slopes. These ridges are lateral moraines, containing bowlders of sandstone, limestone, and quartzite. The sandstone and limestone bowlders are distinctly weathered, and the ridges have been somewhat eroded by streams. The moraine on the east slope of the canyon stands out as a conspicuous ridge blocking the course of a small tributary stream. Between the lateral moraines, and still farther downstream, there are considerable quantities of washed material. At a few places portions of this outwash material, or valley train, appear as terrace remnants. The frontal or terminal moraine, which must have been associated with the lateral moraines, and which must have crossed the valley joining their lower ends, has been entirely carried away by the stream.

About 1½ miles upstream from the lower ends of the moraines in the canyon of South Fork a sharply marked morainic ridge of very fresh material extends across the valley. This moraine (see Pl. III, *B*) is peculiar in that it is made up almost entirely of large, angular material. These huge blocks are of limestone, and some of them are as much as 8 feet in diameter. Among them are smaller masses of shale. This material was removed by the ice from the Carboniferous rocks (Pennsylvanian or "Upper Coal Measures"), which outcrop a few rods farther upstream. The angularity of the limestone blocks and the fragile condition of the associated shales indicate clearly that the material was carried on the top of the ice rather than at its base. At its downstream margin this moraine is fully 100 feet above the bottom of the valley, but on its upstream side it does not stand so high above the valley floor. This difference is due in part to the deposition which the moraine has caused on its upstream side. Throughout most of the year the stream easily finds its way by underground routes through the moraine, but during the flood season it is somewhat ponded. The moraine, however, is of material too loose to cause much of a lake, and as yet the water has not risen high enough to overflow.

Above the morainic dam the valley is heavily filled with drift which has been but slightly modified since it was left by the ice. Massive moraines are banked on either slope, and at intervals recessional ridges cross or partly cross the gorge. The limit of drift is fully 800 feet above the valley bottom. In this part of the valley the stream has cut but a narrow notch in the drift deposits. Near the head of the main canyon of South Fork the drift is composed entirely of quartzite and sandstone.

A. ROUNDED SUMMIT ON RIM OF UINTA BASIN.

B. TERMINAL MORAINE ON SOUTH FORK OF WEBER RIVER, LOOKING DOWNSTREAM.

C. MORAINE IN WEBER CANYON, NEAR HOLIDAY PARK.

Showing topographic unconformity—broad valleys above the moraine and small, inconspicuous valleys below.

The basin (No. 5) of the main canyon is bounded by steep slopes, which rise to elevations of 10,000 feet above sea level. The floor is over a mile in diameter and a portion of it is above the 9,500-foot contour. This basin is small relatively to many in the range, but being favorably situated furnished a glacier which descended to an elevation of 7,300 feet before melting and reached a maximum length of a little over 4 miles. It contains several well-marked morainic ridges, but a dense forest growth obscures details over the greater portion of the floor. One small lake lies among the drift deposits of the basin and several marshes remain where lakes or ponds formerly existed.

A comparison of the valley and of the glacial deposits above and below the angular frontal moraine suggests strongly that the drift deposits downstream from that moraine belong to an earlier glacial epoch than those above. This view is supported by the difference in amount of weathering of the material, the difference in the amount of stream erosion and deposition since glacial times, the absence of the outermost terminal moraine, and the outwash in the valley below the angular terminal moraine. According to this interpretation the angular moraine marks the position of the ice at its maximum extension during the last epoch and was the source of material for the valley train associated with this moraine. The main glacier of the last epoch was a little over 3 miles in length, reaching its lower limit at 7,500 feet.

Two minor glaciers which originated in basins 3 and 4 joined the ice in South Fork. Basin 4 is very small, scarcely more than half a mile in diameter, and yet it received enough snow to form a small tongue of ice which reached the main canyon. Most of the moraines of this glacier are in the lower portion of its course. They rest on the valley slopes and are now heavily clothed with vegetation.

The ice that formed in basins 3 and 4 coalesced, forming a continuous mass, and the ridge that now separates these basins suffered somewhat from ice abrasion. The ice that formed in basin 3 left very heavy moraines throughout its course, and at the lower end developed morainic ridges which extend slightly into the main valley of the South Fork. The deposits are made up of quartzite, sandstone, and limestone, the limestone being much weathered. About 1 mile above the junction of this canyon with the main valley a distinct drift ridge crosses the tributary valley in the manner of a recessional moraine. On this moraine weathered limestone bowlders stand out conspicuously. Above the recessional moraine numerous minor moraines swing into the valley from the main laterals high on the slopes. In the catchment area there are at least three small lakes in drift basins.

During the first epoch the ice from basin 3 probably joined the ice of South Fork and moved a short distance downstream. In the last epoch the ice moved nearly to the main valley before melting.

A tributary joins South Fork from the east just above the junction of the stream from basin 3. This tributary was so located that when the glacier in the main channel reached it a small lobe of ice from the main glacier advanced a few rods up the tributary valley and left a considerable mass of glacial drift in the lower portion of the tributary. Above this deposit this tributary shows no signs of glaciation, but, on the other hand, retains an unmodified erosion form with angular talus slopes and alluvial fans.

SMITH AND MOREHOUSE CANYON (BASINS 6 TO 12).

The report on the glaciation of Smith and Morehouse Canyon involves a portion of Weber Canyon, for the ice which moved down the former advanced for some distance into the latter.

Smith and Morehouse Canyon is the largest canyon tributary to the Weber in the Uinta Mountains. It is located east of South Fork and west of the bifurcated head of the main canyon in the east-central portion of the Coalville quadrangle. Six catchment basins, Nos. 6 to 12, inclusive, contributed to the ice in Smith and Morehouse Canyon. All of these basins are above 9,000 feet in elevation, and most of them are above 10,000 feet. The canyon is narrow, steep sided, and rugged in its upper part, but farther downstream it becomes more open.

Weber Canyon is not truly in the Uinta Mountains, but at their north margin, yet it is bordered on the north by very considerable elevations. This canyon is broad and open near the mouth of Smith and Morehouse Canyon and for several miles upstream and downstream from that point.

The morainic deposits in the Weber extend 3 miles downstream from the mouth of Smith and Morehouse Canyon. They consist of separated remnants of lateral moraines lodged on the lower slopes of the canyon. At their downstream termini their crests are not more than 100 feet above the stream, but they gain in elevation upstream until, at the mouth of Smith and Morehouse Canyon, their tops stand between 400 and 500 feet above the valley bottom.

The discontinuous nature of these moraines is due to erosion at the mouths of the tributary valleys which the moraines formerly blocked. At each of these valleys on the north slope of the Weber, and at one or two on the south slope, narrow V-shaped notches have been cut through the moraines. These valleys, which are narrow below and broad above the morainic line, present a good example of topographic unconformity[a] and indicate the lesser age of the erosion topography on the lower portions of the slope. The erosion of the moraines has resulted in the development of a number of alluvial fans that extend into the valley.

It is a conspicuous fact, illustrating the amount of postglacial erosion in this part of the Weber, that the terminal moraine which must have been associated with these lateral moraines is wanting.

The position of the downstream termini of the lateral moraines would indicate that the ice which formed there descended to about 7,100 feet. Between the lateral moraines in Weber Canyon, extending even farther downstream than their lower ends, lies a heavy alluvial filling 30 to 40 feet thick. This alluvium appears now in the form of stream terraces, which are best preserved on the south side of the main stream. These terraces continue upstream to and above the mouth of Smith and Morehouse Canyon, but not up that canyon. Both in the main canyon and at the mouth of the tributary the terraces terminate at morainic ridges. The morainic ridges at the mouth of Smith and Morehouse Canyon are concentric in form and rise 5 to 20 feet above the alluvium about them. Their form and position indicate clearly that the ice which made them moved down the Smith and Morehouse Canyon. In the main valley the termination of the terraces is at the downstream margin of a series of moraines developed by the glacier of the main Weber Canyon. The terraces are interpreted as remnants of an immense valley train.

Upstream for a distance of about 1 mile from the morainic ridges at the mouth of Smith and Morehouse Canyon, that canyon is bordered by nearly vertical walls, so steep that no considerable masses of drift are lodged upon them. The floor of the canyon here is masked by a deposit of ground moraine, with a rolling topography. At the upstream terminus of the ground moraine belt, at an elevation of about 7,500 feet, there is an immense frontal moraine. This moraine consists of a complex of drift ridges, which, with the exception of a narrow V-shaped notch, completely cross the canyon. The thickness of the deposit is somewhat over 100 feet, and its width, measured along the course of the stream, is half a mile.

Upstream from the frontal moraine, for 2½ miles, the canyon bottom is free from heavy deposits of drift. Over a large portion of it there is a broad flat which may have been covered by waters ponded by the moraine. This portion of the canyon has been surveyed for a reservoir site, as a dam 50 feet long and 40 feet high at the moraine would hold a large body of water in the canyon.

From the massive frontal moraine lateral moraines extend for some distance up the canyon. These side moraines are lodged high on the canyon slopes. The west lateral is discontinuous, because the steepness of the slope did not permit the lodgment of any large quantity of drift. The east lateral is a continuous ridge down to the outlet of basin 12, and from that point downstream it is discontinuous. At the forking of the stream there are morainic deposits between the main and the tributary from basin 6, which are somewhat of the nature of a medial moraine. Farther upstream the canyon becomes very rugged. Rock ledges cross the stream course, caus-

[a] Salisbury, R. D., Jour. Geology, vol. 12, p. 707.

ing falls and rapids. The canyon walls are so steep that little or no drift is lodged upon them, and the high gradient of the bed enabled the ice and afterwards the stream to carry away most of the loose material from this part of the canyon. The bare rock ledges crossing the stream course make travel here very difficult. There is no road, not even a trail, through the upper portion of the canyon.

Basins 6 and 7 lie west of the main canyon and yet near the crest of the range. They are protected by high walls, and served as catchment areas for large quantities of snow. The route through the canyon heading in basin 6 is over irregular deposits of drift, which, as exposed in the stream cuttings, reach a thickness of at least 100 feet. The entire floor of the canyon and basin is masked by deposits and so overgrown with dense forest that it is impossible to map any details.

Basin 7 shows some bare rock patches from which the loose material has been removed by ice, but drift is scattered over most of the floor. This basin is also overgrown by a pine forest, which is practicably inaccessible for lumbering purposes because of the ruggedness of the canyon below. The ice which formed in this basin joined that from basin 6 and then moved on to the main canyon. It was also joined to the ice on the south slope of the range over a low pass at the head of the basin.

Basins 8 and 9, at the head of the main canyon, are broad, amphitheatral areas that stand at elevations of about 10,000 feet, and are bordered by precipitous walls ranging in height from 400 to 1,000 feet above the floors of the basins. Most of the loose material has been swept from the floor of basin 8, which near its head comprises a large area, fully a square mile in extent, in which the bed rock is exposed and beautifully striated and polished. Just below the crest line of the range in basin 8 three small lakes lie in rock basins that indicate vigorous ice action at the very beginning of movement. The low passes between this basin and the heads of Boulder and Shingle creeks, on the south slope of the range, were covered by ice, and the surface of the rock at the former divide is striated. The floor of basin 9 is clothed with a pine forest, which indicates at least a thin deposit of loose material. The ice in this basin was continuous with that on the other side of the range, in North Fork of Provo River.

Basins 10, 11, and 12 lie east of the main Smith and Morehouse Canyon and yet above the 9,500-foot contour. Each of these basins contributed ice to the main canyon and each has been somewhat modified by the action of the ice. The basins are cirquelike in form and contain morainic deposits. Downstream from these basins, between them and the main canyon, there are lateral moraines. The morainic deposits in these basins and in the associated canyons are heavily clothed with timber, which obscures details in the arrangement of the drift deposits. Each of these tributaries from the east is a "hanging valley," their lower ends being from 300 to 500 feet above the main valley at the junction points.

The moraine about 1 mile above the mouth of Smith and Morehouse Canyon is interpreted as the terminal moraine of the last glacial epoch. The deposits upstream from this moraine, including those in the basins, belong to the same epoch. The deposits downstream, to the mouth of the canyon and thence down the Weber, are interpreted as belonging to the earlier glacial epoch. The latter deposits are but remnants of a former continuous system of moraines, the outermost portion of which, as already stated, has been entirely removed. The alluvial terraces in Weber Canyon are valley train deposits, made by waters issuing from the ice when the terminus was at the mouth of Smith and Morehouse Canyon.

The moraines where the valley-train deposits begin are interpreted as recessional moraines of the earlier epoch. It is certain that the ice edge stood for a long time where these moraines lie—long enough to furnish vast quantities of alluvium to the Weber Valley. There is, however, no positive data at hand for crediting these moraines and the associated outwash to a distinct glacial epoch and thereby making a threefold division of the glacial deposits associated with Smith and Morehouse Canyon.

At its maximum extension the ice of the earlier epoch was nearly 11 miles long and descended to the 7,100-foot level. In the later epoch the ice was about 7 miles long and descended to 7,500 feet. The average thickness of ice in the basin was about 400 feet and the maximum thickness of the glacier was about 700 feet.

WEBER CANYON SYSTEM (BASINS 13 TO 18).

The glaciated portion of Weber Canyon below the mouth of the Smith and Morehouse tributary has already been considered. Upstream from the mouth of that tributary, the main canyon continues to be broad and open for nearly 7 miles. Then the canyon becomes noticeably narrower, for at this place the stream and the ice have had to cut through the upturned layers on the flanks of the range. Upstream from the Holiday Park area, which is located near the constricted portion, the canyon has the symmetrical U-shaped form characteristic of glaciated gorges. Near Holiday Park three tributary canyons join the Weber. Each of these tributaries heads in a large catchment basin, high in the range, and each contributed ice to the main canyon during the earlier, more extensive epoch of glaciation. Each of these tributary canyons has been widened and deepened by ice abrasion.

Half a mile above the mouth of Smith and Morehouse Canyon a distinct series of glacial deposits appears in the main Weber Canyon. In the midst of the canyon there are terminal moraine ridges which are partly buried by valley train material. These ridges are crescent-like in form, with the convex curve downstream. They contain immense quartzite blocks and bowlders, 5 to 6 feet in diameter, which must have traveled several miles on or in the ice and may have come from points near the crest of the range 12 to 13 miles up the canyon. Where the lateral moraines join the terminal on either slope they are less than 100 feet above the water of the river, but their elevation increases upstream until at a distance of 6 miles from the terminal moraines they are 600 feet above the water. These lateral moraines represent, therefore, an average slope of 100 feet per mile for the surface of the ancient glacier that deposited them. The ice moved over a gradient of not more than 35 feet per mile in the same portion of its course, and therefore the thinning of the ice in the lower 6 miles amounted on the average to about 65 feet per mile. The sandstone and limestone material of these moraines is much weathered, but the hard quartzite, which constitutes by far the greater number of the bowlders, shows little or no disintegration. The moraines, however, show deep lines of erosion, comparable to those commonly found in the older drift of the region, and from these erosion lines large quantities of material have been washed into the valley and deposited along the sides as alluvial fans. Above the moraines are broad valleys which were developed chiefly in preglacial time. Below the crest of the moraine the erosion lines are not so well defined. The topographic unconformity here is shown in Pl. III, *C*.

From this system of moraines a valley train extends downstream and blends into the alluvial deposits made by the ice which stood at the mouth of Smith and Morehouse Canyon. The alluvium is composed of sands, gravels, and cobblestones, which were but poorly sorted by the torrential waters issuing from the glacier. On the canyon floor above the terminal moraine there are some irregular hills or mounds of drift which may be classed as ground moraine.

At the mouths or in the lower portions of the several tributaries about Holiday Park and also in the main Weber Canyon there are distinct systems of younger, fresher moraines. The twofold division of the morainic deposits in the Weber leads to the interpretation that the outer series belongs to an earlier epoch than the inner series.

WEST FORK OF WEBER CANYON (BASIN 13).

The canyon of the West Fork of Weber River heads 3 miles north of the main crest line of the range and extends about 4 miles in a northeasterly direction. It is of broad, open, U-shaped form, with side walls smoothed by glaciation. The structure of the north slope of the range expresses itself in a series of asymmetrical ridges in the bottom of the valley and in the divides to the east and west. The rock is reddish-colored quartzite interbedded with grits and argillites, and the drift is composed of the same materials in a broken, worn, and comminuted condition. At the mouth of the gorge heavy moraines lie on the side slopes. These moraines appear as three ridges on the opposite sides of the valley, the highest pair of which are nearly 1,000 feet above the stream where it joins the main Weber River.

Between the lateral moraines at the mouth great masses of drift cross the valley in the fashion of a terminal moraine, representing the maximum advance of the ice in this canyon

during the later glacial epoch. Upstream from the terminal moraine the valley bottom is heavily masked with drift. At places the drift approaches the recessional ridgelike form, crossing the valley, but the ridges are poorly defined and are obscured by other heavy deposits about them. The valley walls are stripped of all loose material to a line within 100 feet of their crests, indicating that the glacier which moved down the gorge was nearly 1,000 feet thick.

The basin is about 2 miles in diameter and is protected by precipitous walls of red quartzite on the south, west, and east sides. Most of the loose material has been removed from the catchment area, exposing bed rock over a large part of the basin floor. The bed rock is scored by abundant glacial striæ and grooves. The direction of these markings is that of the canyon. Among the rock exposures, in depressions which may have been deepened by ice action, there are at least four small lakes. At other points in the basin swamps and marshes indicate the former presence of bodies of standing water. The ice collected in this basin to a depth of at least 500 feet.

MIDDLE FORK OF WEBER CANYON (BASIN 14).

In the tributary which has its source in basin 14 a fresh series of morainic deposits swings across the valley at about the 8,100-foot level. Below these deposits the valley is broad and open and contains large quantities of alluvium. Above the moraines other heavy deposits of drift cross the gorge as ridges convex downstream, in the form of recessional moraines. These moraines have been sharply notched by the stream in post-glacial time, and are therefore not continuous across the valley, but are represented by spurlike ridges advancing from opposite sides of the valley to the modern stream gorge. At least six of these recessional ridges were left in the track of the retreating glacier. The valley is now beautifully U-shaped, and in its upper portion the sides are at many places too steep to permit any lodgment of drift. The upper limit of ice action is defined by the upper limit of smoothing and cleaning on the walls of the gorge. Above the line of ice action the mountain slopes are rugged, showing the asperities due to a long period of weathering, while below that line the surfaces are more even, roughnesses have been largely removed, and at places the valley walls, hundreds of feet above the stream, appear to have been polished by the advancing glacier.

In the bottom of the canyon, upstream from the terminal and recessional moraines, the bed rock is at many places exposed. The truncated beds of quartzite dipping to the north, opposing the advance of the glacier, suffered intense wear. At places their surfaces are deeply grooved and striated; at others they are beautifully polished. The general effect of the erosional work in the bottom of the canyon, after reducing the roughness which must have existed, was to produce a series of roches moutonnées on a gigantic scale, which extend for miles on both sides of the stream. The amount of loose material in the canyon becomes less and less upstream, toward the basin. The ice so thoroughly cleaned off and carried away the disintegrated material that the upper portion of the basin comprises acres of bare rock surfaces. These surfaces are so completely polished, grooved, or striated that it would be difficult to find a square foot of bed rock in place which did not show distinct signs of ice action. There are at least five lakes in this catchment area, three of which are in basins of solid quartzite. Mount Watson, a prominent peak in the western part of the range, is one of the four or five peaks bordering this basin which rose above the ice. The rim of the basin is therefore not continuous, but is broken by low passes through which continuous bodies of ice connected the glaciers on the north slope with those on the south slope of the range.

Being joined by three low passes with areas that were occupied by the great ice cap of the western portion of the range, basin 14 may well be considered a portion of the region covered by that mass of ice. About Mount Watson the upper limit of ice action was determined at 10,800 feet, which means that a thickness of at least 300 feet of ice rested on the cols between basins 14 and 118 and basins 14 and 120. Most of the loose material has been swept away from these cols, and in the one just north of Mount Watson there is a chain of eight glacial lakes in a series of rock basins. Striæ on this col within a few rods of one another point in opposite directions, illustrating the directing influence of the rock surface beneath the glacier. These striæ run at right angles to the rim of the basin, while those in the bottom of the canyon farther

downstream coincide in direction with the general trend of the gorge. The collecting area includes about 6 square miles. During the last epoch the glacier descended 5½ miles from the crest. The maximum thickness of ice in the basin was at least 800 feet, but in the canyon the maximum thickness was not less than 1,200 feet.

THE MAIN WEBER CANYON (BASINS 15, 16, AND 17).

Less than a mile above Holiday Park massive morainic ridges cross the main valley in a manner that suggests the position of the terminus of the ice tongue which advanced down this gorge. Lateral moraines appear high, and at increasing height upstream, on both sides of the gorge. On the divide to the west, between this gorge and Middle Fork, a medial moraine stands 1,200 feet above the stream, indicating no less thickness of the ice that once occupied this canyon. The point where this measurement was made is 2½ miles above the terminal of the last epoch in the main gorge. If this lofty medial belongs to the deposits of the last epoch, the glaciers of these canyons must have ended with very steep fronts, the surface declining nearly 1,200 feet in about 2½ miles. Heavy morainic filling continues upstream to the basin. In fact the valley is so choked with glacial débris, both on the sides and on the bottom, and so heavily clothed with forests, that travel through the canyon with horses is extremely difficult. The details of morainic forms are entirely obscured, but as seen from the lofty peaks at the head of this area the salient features of the catchment basins and the symmetrical U-shaped form of the gorge are clearly defined.

Basin 15 has been so well cleaned out that the floor is for the most part bare rock. The inclined quartzite beds of the north slope of the range outcrop as parallel ridges in the basin. These rock ridges have been beautifully polished, grooved, and striated, giving the general effect of elongate roches moutonnées. Between the ridges, in rock basins partly scoured out by the ice, there are as many as eight lakes. (See Pl. V, *A*.) This basin is amphitheatral in form, with precipitous boundary walls, which are notched at two points where the ice and snow were continuous with the ice and snow of basins 14 and 119.

In the pass between basins 15 and 119 most of the loose material has been swept away and the rock surfaces have been striated and show marked glacial erosion in opposite directions at points a few rods apart.

The upper limit of positive traces of ice work at the head of basin 15 is 10,700 feet. Above that elevation talus masks the mountain slopes, obscuring any possible higher marks of glaciation, but it is certain that there was a considerable thickness of ice above 10,700 feet when the striæ at that elevation were made.

The main basins 16 and 17 of the Weber glacier are very poorly defined. They blend with the basins of the Provo and the Du Chesne and constitute a portion of the ground covered by the great ice cap that centered about Bald Mountain. The basin region that is now drained by the headwaters of the Weber is about 7 square miles in extent, and the snow collected in that area contributed to the main Weber glacier. In the collecting area the rock surface is in part exposed and in part covered with a mantle of drift that is variable in thickness and hummocky in topography. The bare rock surfaces have been distinctly affected by glacial action and in places so gouged out that lake basins have been formed. At least 4 of the 18 lakes now located in the collecting area of the main Weber glacier are in rock basins. The remaining lakes, not in rock, are in basins formed by the uneven deposition of drift. The portions of the catchment area where bare rock surfaces are not exposed or where lakes do not exist are heavily wooded. The upper line of abundant trees coincides with the upper line of glaciation in this crest region. From favorable elevations the more prominent morainic ridges on the floor of the basin may be located.

FISH LAKE CANYON (BASIN 18).

Fish Lake Fork of Weber Canyon heads just north of the main crest of the range and extends about 5 miles in a northwesterly direction, joining the main Weber Canyon just below Holiday Park.

A. FLOOR OF BASIN 15, LOOKING NORTH.
Showing bare rock surfaces and a series of rock-basin lakes.

B. CATCHMENT BASIN 18, LOOKING SOUTH.

The canyon is rather narrow at the mouth and for about 2 miles upstream to the point where it divides into two forks. The west fork keeps close to the west wall of the basin and has its source at its western margin; the east fork heads at the extreme eastern margin of the basin and follows its eastern wall. The west fork descends steeply from the catchment basin, making in its course three abrupt drops of 100 feet or more each. The east fork descends by a longer route and over a more gradual slope, its bed not being interrupted except by rapids. The entire drop from the head of the basin to the mouth of the canyon is 2,600 feet. The structure of the canyon is that common to the north side of the range, the beds dipping to the north. The rock is mainly quartzite, interbedded with grits and argillites. On the right-hand slope of the east fork limestone bed rock is found.

Fish Lake Canyon was vigorously glaciated. A well-formed lateral moraine rests against the mountain side south of the stream at its mouth. This makes a decided bend around a mountain and joins a high lateral moraine lodged on the crest between Fish Lake and Weber canyons. On the north side of the canyon lies a lateral moraine, not so well defined as the one on the south, on account of the steepness of the slope, but extending upstream from the canyon's mouth for a distance of nearly a mile. These outer moraines are interpreted as belonging to the earlier epoch.

At a point 1 mile from the mouth of the canyon a heavy moraine, much less weathered than the laterals described above, extends across the canyon and joins the lateral moraine on the south crest. This apparently marks the limit of ice during the second epoch. In the next half-mile above it four small but distinct drift terraces succeed one another on the south side of the valley. These appear to mark the position of the sides of the ice during stages of retreat. No distinct recessional moraines cross the canyon below the catchment basin, but both forks of the canyon are so heavily clogged with drift that the bed rock is nowhere exposed. Some drift in the small tributary gullies coming into the main canyon from the north side is so distributed as to indicate that small tongues of ice moved from the main canyon up these tributaries.

The catchment basin for the two forks of Fish Lake Canyon is a high, flat-bottomed basin about 2 miles long and nearly as wide. (See Pl. V, *B*.) It is roughly semicircular in outline and is bordered by steep rock walls that are more or less masked by talus. The general elevation of the floor of this basin is 10,200 feet. The ice filled the basin to a maximum thickness of about 500 feet.

The catchment area contains seven lakes and a number of old lake flats. One of these lakes drains into the east fork, but the others drain into the west fork along the lines marked on the map. The lakes are separated by ridges that are thickly covered with large, rounded quartzite bowlders. Fish Lake, the largest lake in the basin, lies at the foot of a precipitous wall, the talus slopes from the cliff above descending into its waters. It is held in by a ridge of morainic material. Below the next large lake (Pl. VI, *B*) north of Fish Lake there is another ridge, which extends for about half a mile across the basin and has the general form of a terminal moraine. It is peculiar in that it is composed almost entirely of large, angular blocks of quartzite, among which a few slightly rounded bowlders of the same rock are scattered. This large deposit of angular material, massed together in this form and place, suggests that the ice of Fish Lake basin may have advanced to this point after a prolonged retreat or possible disappearance. Certainly the amount of talus that has accumulated at the head of Fish Lake basin since glacial time would not form a larger moraine were ice to carry it out the same distance.

In the earlier epoch the ice from Fish Lake Canyon joined the main Weber glacier. At this junction it was nearly 1,000 feet thick. During the later epoch the ice formed in this basin did not reach the main canyon. The moraine of angular material in the basin is suggestive of a threefold division of the drift deposits, but three epochs have not been conclusively determined anywhere in the range.

THE BEAR RIVER SYSTEM (BASINS 19 TO 34).

Bear River with its several tributaries drains the northwestern portion of Hayden Peak quadrangle. The main valley and the tributaries in the country north of the range are broad and open, but those branches that head near the crest of the range flow through deep canyons in their upper courses. In the valleys of certain of the lower tributaries that lie north of the range there is evidence of some névé work and a great deal of landsliding. These features will be considered later in the report. At the head of each of the tributaries there are capacious catchment areas which, even on the topographic map, clearly show evidences of ice action. From these collecting grounds ice moved down the north slope, scouring out the canyons and giving them U-shaped forms. Sixteen catchment basins of this system contained ice, and all but two of these basins contributed to the glaciers that united and occupied the valley of the Bear.

WEST FORK OF BEAR RIVER (BASIN 19).

At the head of West Fork of Bear River there is a poorly defined basin which contained some ice during one of the glacial epochs, presumably during the earlier. The ice formed a little below an elevation of 10,000 feet and moved down to an elevation of 9,400 feet. The deposits have been greatly modified by postglacial erosion and are therefore not conspicuous. Remnants of lateral morainic ridges remain on the sides of the valley about 1¼ miles below the head of the basin. In these moraines there are striated stones. The morainic material consists of quartzite, sandstone, argillite, and limestone. The limestone appears only in the deposits farthest downstream, for the ice did not cross outcrops of that rock until it reached the lower portion of its course.

Postglacial accumulations obscure the margin of the basin, so that it is difficult, if, indeed, possible, to determine just the limit of the ice. The entire area about the basin, except the higher peaks and precipitous slopes, was undoubtedly covered with perennial snow fields during the glacial period.

There is no suggestion of a twofold division of the deposits associated with basin 19, and since it is one of the less favorably located basins and since the deposits are apparently older than those undoubtedly left by the later ice, they have been classed with the deposits of the earlier epoch of glaciation.

BEAR RIVER VALLEY.

At the Utah-Wyoming line, near the north boundary of the Hayden Peak quadrangle, the valley of Bear River is a little more than 2 miles wide. At this point the valley is filled with a coarse alluvium in which the stream has intrenched its course to a depth of about 40 feet. The portion of the valley that is at present occupied by the stream is therefore a narrow gorge, at few places more than 100 yards wide, and at many points much narrower. The sides of this gorge nearly everywhere in its course are as steep as the alluvium of which they are composed will stand. Along the gorge at many places are narrow flood plains, but at other places the stream entirely occupies the gorge.

The alluvial material is largely quartzite and sandstone and the finer materials resulting from the disintegration of these rocks. Some limestones and some grits are found in the alluvium. This material is just such as might have come from the glacial drift and yet just such as might have come from the Tertiary conglomerates. Furthermore, it is the only material that could be obtained by streams crossing from the crest of the range to the lowland. The composition of the alluvium therefore furnishes no clue to its history, so that its relationships and position must be relied upon to denote its origin.

The present topographic form of these alluvial deposits is that of broad, flat terraces extending for several miles along the course of the stream. The downstream limit of these deposits has not been determined, although it is known to lie far beyond the region studied. Upstream these deposits terminate at the downstream margin of morainic remnants of the earlier epoch of glaciation. (See Pl. VI, *A*.) These moraines are at an elevation of 8,200 feet. As these

A. OUTWASH PLAIN IN VALLEY OF BEAR RIVER, LOOKING SOUTHWEST.

B. GLACIAL LAKE IN BASIN 18.

Held in by a morainic ridge of angular material.

morainic remnants are approached from the north, the surface of the alluvium rises and appears to overlap the marginal portion of the moraines. The relationship is just such as is common between terminal moraines and outwash plains associated with the interior ice sheet.

Farther upstream there are other alluvial terraces, younger in age and even in part lower than those already described. These terraces continue, with some interruptions, up the three main forks of Bear River and terminate abruptly at other fresher terminal moraines that cross the tributary canyons. Above the younger terminal moraines there are no alluvial terraces.

The upland bordering Bear River valley at the Utah-Wyoming line has a gently rolling erosion topography, sculptured from the easily worked Tertiary formations. A few miles farther south the valley slopes become somewhat irregular in form and at places have a hummocky topography. There is nothing, however, in this topography, or in the material, that demonstrates glaciation, and it is believed that the forms may all have been produced by landslides in the Tertiary conglomerates.

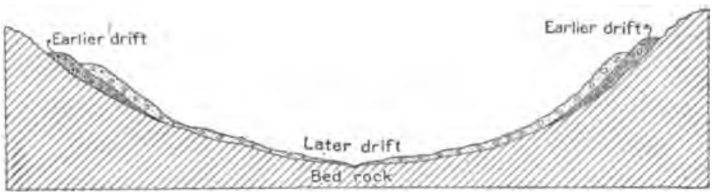


FIG. 2.—Diagrammatic section of East Fork of Bear River, showing relatonship of older and younger moraines.

At the upstream margin of the outer terrace the moraines have the characteristic forms and positions of such deposits. They mask the lower slopes of the valley, appear as irregular heaps in the midst of the valley, and continue upstream to the younger terminal moraines in the different tributaries. In fact, these older moraines extend still farther upstream and stand higher on canyon walls than the younger lateral moraines. (See fig. 2.)

The glacial deposits crossing the valleys where the upper alluvial terraces end upstream are interpreted as terminal moraines of the later ice advance, representing the position of that ice at its maximum extension. The alluvial deposits, now appearing as terraces, are therefore interpreted as remnants of valley trains which had their origin at the ends of the glaciers that rested in East, Stillwater, and Hayden forks during the last glacial epoch. These terraces are therefore much younger than the drift deposits bordering them, having been laid down in the valley which was excavated during the long interglacial epoch following the deposition of the earlier drift. The outer terraces associated with the older moraines are interpreted as remnants of a valley train of the earlier epoch.

HAYDEN FORK (BASIN 20).

The portion of Hayden Fork above the terminal moraine of the later glacial epoch is yet to be described. This moraine crosses the valley at an elevation of about 8,600 feet, near the northern limit of the canyon-like portion, about 10 miles from the crest of the range. Throughout these 10 miles the canyon has the beautifully U-shaped form that is characteristic of glacial canyons. The terminal moraine is composed chiefly of quartzite, but contains a considerable admixture of sandstone, grit, and limestone. The quartzite, sandstone, and grit come from the pre-Cambrian formation, and may have been procured from the crest of the range or almost anywhere in the upper 5 miles of the canyon. The limestone was procured from the upturned "Coal Measure" beds and does not appear in the drift of the later epoch except in the lower 3 miles.

On the valley slopes upstream from the terminal moraine of the last epoch lateral moraines are lodged. These side moraines are ridgelike in form and continuous with the main terminal moraine ridge. Like the terminal moraine, they are but little eroded, and differ in this respect from the moraines farther down the valley which have already been described.

A number of recessional ridges cross the valley floor in the manner of terminals, though they are not usually so well defined nor so prominent. Just above each of these moraines, upstream, a broad, flat meadow crosses the valley, marking the site of a former lake which was held in for a time by the moraine. Where the stream crosses the moraine at the lower end of each of these meadows it has cut a narrow notch, 10 to 15 feet deep.

Farther upstream the east wall of the canyon is so steep that little or no drift could lodge upon it. A well-pronounced moraine lies at its base, rising 500 feet above the stream, but the upper limit of ice work is not shown by the limit of drift, for the mountain side is cleaned off by the glacier to a much greater elevation. It would have been impossible to examine this mountain wall at close range, but judging from the position of the moraines on the west slope and from the cleaned-off condition of the east wall, it is safe to state that in the upper portion of the Hayden Fork canyon the ice was fully 1,200 feet thick. The moraines on the west slope are massive and show four or five distinct ridges that branch off from the main lateral and turn in toward the stream.

Still nearer the basin region lies a belt of drift deposits which has a distinctly hummocky topography. The material is such as could have been derived from beds of the pre-Cambrian quartzite, and having come but a short distance it contains many angular fragments. The morainic material in the bottom of the canyon which could not be interpreted as lateral moraine has been classed as ground moraine.

Upstream from the hummocky belt is the catchment basin (No. 20) that furnished the ice for the glaciers of Hayden Fork. The basin is now divided by a medial moraine which extends downstream for a distance of 3 miles. The entire catchment area includes at least 6 square miles, but is not sharply defined, being a portion of the area covered by the great ice cap which centered about Bald Mountain.

About the head of Hayden Fork there are a number of rugged peaks which rose above the ancient snow fields as nunataks. Around these nunataks and over the cols at the head of the canyon the ice was sufficiently active to remove most of the loose material, to smooth and to striate the rock surfaces, and even to gouge out basins in the solid rock, some of which are now occupied by lakes. Striæ were found on these peaks as high as 11,500 feet, indicating that but a few hundred feet of rock rose above the ice. Still less must have appeared above the snows.

In the catchment area below the main divides there are at least nine lakes, of which four are in rock basins. About the rock basins, polished surfaces and striæ are of common occurrence. Roches moutonnées also were seen at many places in the basin. The striæ are parallel to the general direction of the canyon.

BASINS 21 AND 22.

Basins 21 and 22 are located between Hayden and Stillwater forks, several miles north of the main crest line of the range, but at sufficient elevations to have furnished ice which helped to form Bear River glacier. The valleys through which this ice moved are U-shaped in form and contain heavy deposits of till. Moraines are banked on the valley slopes and lodged in the bottom to such an extent that bed rock was nowhere seen and is probably nowhere exposed. These moraines are now overgrown with a dense forest, which makes travel very difficult and detailed mapping in the basin or valley impracticable. Near the mouths of these tributaries the lateral moraine ridges are pronounced, rising 20 to 40 feet above their surroundings. Those from basin 21 merge with the moraines in Hayden Fork and those from basin 22 with the moraines in Stillwater Fork. The material handled by the ice in these valleys was quartzite, sandstone, and grit.

The catchment areas are cirquelike in form, with steep bounding walls, now talus clad. Basin 21 and the short valley below it is now a hanging valley on the side of Hayden Fork, and its mouth is still somewhat blocked by the lateral moraine of the larger glacier. In basin 22 three small lakes nestled among the trees are held in by the drift deposits.

The well-preserved condition of the moraines in these valleys and their relations to the younger moraines in the larger canyons, as well as the lakes among the deposits, lead to the conclusion that the moraines belong to the later ice advance. Probably these tributary canyons were occupied by ice during both glacial epochs.

STILLWATER FORK (BASINS 23 TO 27).

The ower part of the Stillwater Valley, with its valley train and old moraines on the side slopes, has been described in connection with the valley of the Bear. The younger terminal moraine crosses the valley at the upstream limit of the valley train terraces and at an elevation of about 8,700 feet. This moraine is composed of a number of concentric ridges with more or less heavy deposits of till about them, forming a belt fully half a mile wide.

The view up the canyon from the terminal moraine is through a broad, U-shaped gorge, beautifully symmetric in form, and flanked on either side by distinct morainic ridges. These lateral moraines rise 500 to 600 feet above the stream and increase in elevation above the stream further up the canyon. Minor drift ridges cross the valley as recessional moraines and are separated by meadow lands, the bottoms of former lakes which these moraines held in. The stream, held to a temporary base level by the morainic deposits, meanders through the meadows, and then passing through a narrow V-shaped gorge, which it has cut in the terminal moraine of the later epoch, enters the intrenched portion of its course in the valley train.

The lateral moraines of Stillwater Canyon are at most places well developed and well preserved. They even suggest railroad grades on the mountain sides, getting steadily higher upstream and crossing with almost unbroken form the mouths of tributary gorges. This condition prevails to the lower end of the main catchment basin, No. 25. The bottom of the valley just below the basin is rather heavily filled with drift, and the stream in this part is restricted to a narrow notch which it has cut in postglacial time.

The tributary gorges to Stillwater Fork, heading in basins 23, 24, 26, and 27, are all hanging valleys. Their streams leave the more gentle gradient of their upper courses and, by a series of rapids and falls, rush down the last 500 to 700 feet to the main stream. The rapids and falls are at rock ledges in the beds of the tributaries. Most of the tributary streams, it may be fairly presumed, entered the main canyon during preglacial time by gentle reaches and over gradients that decreased somewhat constantly to the junction with the main stream. The present condition, which is in marked contrast to that normally produced by stream erosion, emphasizes the tremendous amount of work accomplished by these ancient glaciers. The elevation of the mouths of the tributaries above the main stream represents the excess of ice gouging and scouring in the main canyon over that in the tributaries. It may be difficult to believe that a glacier can deepen a canyon by as much as 500 feet, and yet evidence from almost every canyon among the Uintas, from many of the canyons of the Wasatch, and from other regions of ancient or even modern valley glaciers, forces the acceptance of this belief and a better appreciation of the magnitude of glacial erosion. In fact, 500 feet is but a moderate amount of deepening for a glacier to accomplish.

The tributary basins 23, 24, 26, and 27 are all cirquelike and bounded by talus-clad slopes. Their upper portions contain scattered drift, and their lower parts hold heavy drift deposits, both in the midst of the valleys and on the side slopes. Where the drift deposits are heavy the ground is densely forested and the details of drift forms are obscured. Basins 23 and 24 each contain one lake, and basin 26 contains at least three lakes. Basin 25, the main catchment area tributary to the Stillwater glaciers, is one of the most strikingly amphitheatral basins in the whole region. The lowest pass in the rim of the basin is 500 feet above the floor, and the bordering peaks rise precipitously for 1,500 feet. Mount Agassiz and Hayden Peak are on the southwest margin of the basin, and on the east is another peak of equal height with Hayden—12,500 feet. Above the 11,000-foot line trees are almost entirely absent, and the massive red layers of quartzite, interbedded occasionally with green or brown argillaceous beds, are beautifully exposed. The softer beds alternate with the harder, giving bands of talus separated by vertical rock faces, which encircle the peaks. (See Pl. VII, *B*.) The floor of the basin contains between 6 and 7 square miles, and is remarkably level and remarkably well cleaned off. The bare rock surfaces exposed aggregate in area at least one-third of the basin

floor. These surfaces are striated, grooved, and polished, and portions of them have been gouged out sufficiently to hold considerable bodies of standing water.

At least 5 of the 16 lakes, including some too small to be mapped, stand in rock basins. The largest lake, which is half a mile long and is located at the western margin of the basin, lies at the very base of the mountain, the talus from the mountain side falling into the water. Rock basin lakes in such locations are not uncommon in the Uintas and serve to emphasize the vigor of the ice work at the very beginning of movement. At the lower or downstream margin of the basin the morainic deposits are somewhat conspicuous. The average thickness of ice in basin 25 was 600 feet; the length of the later glacier in Stillwater Canyon was 10 miles and its maximum thickness was about 1,500 feet.

EAST FORK OF BEAR RIVER (BASINS 28 TO 33).

The records of the last glacier in the canyon of East Fork of Bear River are similar to those of the last Stillwater Fork glacier. The terminal moraine of the later ice advance crosses the valley at the upstream limit of the valley train terraces. This moraine consists of a number of drift ridges and irregular masses of till, which lodged as a morainic belt across the bottom of the valley. Upstream the valley is U-shaped. (See Pl. VII, *A*.) In the bottom there are considerable flats, suggesting former ponding of the stream. Broad meadows and patches of willows border the stream for 3 or 4 miles above the terminal moraine. The postglacial cut through the heavy morainic dam is a narrow notch a little over 30 feet deep.

Distinct lateral moraines connect with the main terminal moraine ridge and extend up the canyon on both sides. Like the lateral moraines in Stillwater Canyon, these moraines have been but little modified by erosion, and stand out as distinct shelf-like forms on the valley slopes. They cross the mouths of tributary gorges that contained glaciers, indicating that these tributary glaciers must have retreated from the main canyon before the ice in that canyon had left their mouths. Most of these tributary streams have cut small V-shaped notches in the main canyon lateral moraine. Near the younger terminal moraine in East Fork and above the lateral moraines lie remnants of lateral moraines of the earlier epoch. The relationship of these moraines is shown in fig. 2. The upper or older moraines are more deeply eroded than the lower ones. Tributary gorges in the upper deposits end abruptly at the lower moraines in a manner indicating conclusively that they were developed in a period of erosion that preceded the later advance of ice through the canyon and the deposition of the lower moraines. Considerable time must have elapsed while these side gorges in the older moraines were being developed, before the younger moraines were deposited. This is one of the best lines of evidence found in the range for proving a long interglacial epoch. The length of the interglacial epoch must have been many times as long as the time since the last melting of the ice.

The younger lateral moraines of the main canyon reach elevations of 500 to 600 feet above the stream, the heights increasing slightly up to the lower margin of catchment basins 32 and 33, where the canyon walls are nearly vertical and moraines are absent.

Basin 28 is located at the head of a small tributary to East Fork, about 4 miles north of the crest line of the range. This basin stands at an elevation of 10,500 to 11,000 feet, and although small, it furnished a glacier that moved independently for 4½ miles and then joined the main East Fork glacier. The bed of this contributing glacier is U-shaped in form and is heavily masked with drift deposits, which are now obscured by a dense forest. Between the left lateral moraine of this glacier and the right lateral moraine of the glacier from basin 27 a lake stands in what seems to be a low pass or divide which has been blocked by these two moraines.

Basins 29, 30, and 31 are beautifully symmetrical cirques on the west wall of the canyon of East Fork about 1,000 feet above the stream. They appear now as hanging valleys, although they may not have been distinct valleys in preglacial time, but may have been developed by ice that formed high on these side slopes.

A. UPPER PART OF EAST FORK OF BEAR RIVER (BASIN 33).
Showing characteristic U-shaped form of a glaciated canyon.

B. HEAD OF BASIN 33.
Showing high bounding walls.

Massive recessional moraines occur just below the junction of the two forks that head in basins 32 and 33. The inside lateral moraines from these two basins are distinct for a short distance beyond the rock divide, and between them, at an elevation of 500 feet above the streams to the right and left, lie several small meadows and one lake. (See fig. 3.)

The catchment areas of East Fork of Bear River are narrower than many on the north slope of the range, but they are extremely well protected by high bounding walls. (See Pl. VII, *B*.) The ice accumulated in these basins to a depth of at least 500 feet, and, moving northward, cleaned off most of the loose material near the heads of the canyons, reaching a maximum thickness in the canyon of about 1,700 feet and a length, during the later epoch, of 11½ miles. In basin 32 there are two small lakes, and in basin 33 there is one. These lakes lie in shallow basins that are hemmed in by slight drift deposits.

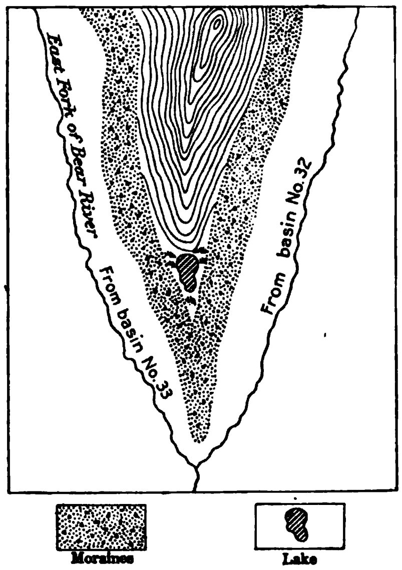


FIG. 3.—Diagrammatic sketch of two lateral moraines joining to form a medial moraine and inclosing a lake basin. East Fork of Bear River.

The East Fork moraines are composed largely of fragments of quartzite; but north of the outcrops of upper Carboniferous and Mesozoic strata sandstone and limestone bowlders become noticeable.

On the east slope of the canyon near Deadman Mountain and on the mountain itself there are outcrops of the Tertiary conglomerate. The difficulty in distinguishing the conglomerate in these outcrops from the drift is not so great as at many other points, as the exposures are high above any known drift and the materials in the conglomerate show water wear and distinct stratification. These exposures give excellent opportunities for study of the conglomerate.

BASIN 34.

This basin lies several miles north of the crest of the range, in the territory between the East Fork of Bear and Blacks Fork of Green River. It may be considered as the source of Mill Creek, a tributary of the Bear. The small glacier that was generated here moved down a narrow canyon to an elevation of 9,500 feet. The glacier was less than 3 miles in total length, and at no place did it reach a mile in width.

The basin, which has an elevation of about 10,000 feet, is now well cleaned out, and the valley has a symmetrical U-shaped form. The chief deposits of drift are at the terminal moraine and in the lateral moraines near the terminal. The drift material is predominantly quartzite.

There is no evidence of distinct glacial epochs in the course of this small glacier, but the general freshness of the deposits and the morainal lakes in the basin suggest that the deposits were made by the ice of the later epoch. It is possible that the ice of the later epoch moved as far down this valley as any earlier ice, and thus may have obliterated any earlier records.

THE BLACKS FORK SYSTEM (BASINS 35 TO 44).

East of Bear River, in the northeastern portion of the Hayden Peak quadrangle, there was a system of glaciers comparable to that which occupied the tributary canyons at the head of Bear River. The main canyons through which the ice moved are now known as those of Blacks Fork, Middle Fork of Blacks Fork, and East Fork of Blacks Fork. The catchment basins which were tributary to this system of glaciers have been numbered on the map (Pl. IV) 35 to 44, inclusive.

The ice that moved down the several canyons in this system united during the earlier epoch near the north margin of the range and the glacier thus formed advanced northward until, at its maximum extension, the ice reached 5½ miles beyond the Hayden Peak quadrangle. This glacier was about 23 miles long.

The outermost moraines in the valley are lateral moraines lodged on the valley slopes, and range in height from 100 feet above the stream at their lower margins to 500 feet above the stream 2½ miles farther up the valley. Downstream from these outermost lateral moraines there are remnants of an outwash or valley train alluvium. The alluvium is much dissected and is recognized with some difficulty. The terminal moraine which must have been associated with these laterals and connected their downstream termini is entirely wanting. The moraines themselves show signs of erosion and the scarcity of ponds and marshes among them indicate that they are of much greater age than those left by the last ice in the region.

Lying between the outermost lateral moraines in the valley of Blacks Fork and extending upstream and downstream there are broad alluvial terraces. Upstream these terraces join the lower margin of a great terminal or recessional moraine, which swings across the valley about 2 miles north of the Utah-Wyoming boundary. These terraces are remnants of a valley train which had its origin at the margin of the ice when the terminal moraine, at which the terraces end, was being deposited. At their upstream termini these terraces stand about 75 feet above the stream, but farther down the valley they come nearer and nearer to the stream level.

The alluvial material is identical in composition with the glacial drift in the valley, consisting of quartzite, sandstone, grit, a little limestone, and finer products from the disintegration of such stones. The material is predominantly quartzite.

The great terminal moraine that crosses the valley where the terraces end blends on either side of the valley with heavy lateral moraines. Portions of these lateral moraines are of the hummocky or knob-and-kettle type, giving an exceedingly rough topography to the valley slopes. Most of the kettles contain meadows or swamps, but a few still hold small ponds. These hummocky morainic belts on the borders of the valley extend upstream to much younger morainic forms that cross the separate forks as distinct terminal moraine ridges.

In the valley between the lateral moraines, and farther upstream, extending to the younger terminal moraines just mentioned, lie remnants of a valley train younger than that which lies between the outermost lateral moraines, and which has already been described. These younger terraces are far less conspicuous than the outer ones and nearly disappear downstream before the older ones begin. They may have extended farther—possibly certain lower terraces within the outer ones represent the younger series—but the evidence on this point is not conclusive.

The entire series of moraines north of the forking is interpreted as belonging to the earlier epoch, and the outermost alluvial terraces are of the same age. The terraces terminating at the younger terminal moraines in the distinct forks are interpreted as later epoch deposits.

THE CANYON OF BLACKS FORK (BASINS 35 TO 40).

The younger moraines in Blacks Fork canyon and the catchment basins remain to be described. The younger terminal moraine is of the hummocky type. This may be accounted for in part by the abundant material which the ice obtained from the Tertiary conglomerate in the last 4 miles of its course and in part by the great breadth of the valley at the point where the margin of the ice rested. The morainic belt extends fully 2 miles upstream from the valley train already described, and is banked on either side of the valley. On the west slope the morainic deposits have an exceedingly rough topography and rise to an elevation of 700 feet above the stream. Among these drift hills are several small lakes.

Upstream from the terminal moraine the canyon has a beautifully U-shaped form. The side slopes have been softened in contour and smoothed off by the action of the ice for several hundred feet above the stream bed. At places these glaciated canyon walls are too steep to permit the lodgment of large quantities of drift, but at other places they bear lateral morainic ridges. The bottom of the canyon contains irregular patches of drift which have assumed a

rolling topography like that of the ground moraines of lowland regions. Above the morainic patches, which at widely separated intervals cross the valley, there are broad meadow lands.

The most conspicuous features in the canyon are the high rock benches or shoulders which have been cleaned off and polished by the glaciers. The highest of these cleaned-off rock benches stands 900 feet above the stream and extends for over a mile along the west wall of the canyon below basin 38. Other benches, 500 to 600 feet above the stream, appear at short intervals along the canyon. All the tributary gorges are hanging valleys, but those numbered 36, 37, 39, and 40 are the most marked. The streams from these tributary gorges descend as cascades down the last 500 feet of their courses. Above the cascades they flow through U-shaped canyons which have very evidently been glaciated. These tributary canyons have a cleaned-out appearance, they contain small moraines and striated rock surfaces, and their heads are of such shapes as to indicate former ice occupancy.

Nearer the main basin the bottom of the canyon is clogged with heavier deposits of drift. The lower margin of the basin is marked by a hummocky morainic belt, like those occurring in similar locations in Weber and Bear River canyons. These hummocky belts at the lower margins of catchment areas must represent a late phase of activity of the ice, and possibly indicate a minor readvance of the glaciers just before the final melting. Above this morainic belt the basin has been well cleaned out. Bare rock surfaces are exposed, and in lower places, in depressions formed by ice gouging and partly by slight lodgments of débris, there are four small lakes. The basin is bounded by bold rock faces which rise 1,500 to 2,000 feet above the floor of the collecting area. Snow may have rested on some of the passes, but no ice action is recorded at such places. The elevation of the floor of the basin is 10,500 feet. The upper limit of the ice action about the rim is 11,000 feet. The Blacks Fork glacier of the later ice epoch was 14 miles long and at least 1,000 feet thick in portions of the canyon. It descended to an elevation of 9,100 feet.

MIDDLE FORK OF BLACKS FORK (BASIN 41).

At the upstream limit of the valley train deposits, near the mouth of Middle Fork, there is a remarkably rough moraine, which is interpreted as the terminal moraine of the later ice epoch in this valley. The morainic belt is fully 1 mile wide, and the maximum thickness of drift, as indicated by topographic relationship, must be somewhat over 300 feet.

Upstream from the terminal moraine lateral moraines are lodged on the slopes. The elevation of these lateral moraines above the bottom of the canyon increases gradually until near the basin, where they are between 700 and 800 feet above the stream. About 3½ miles above the mouth of Middle Fork, at a point about 5 miles from the head of the basin, a peculiarly conspicuous moraine crosses the canyon. This moraine is made up almost entirely of large angular blocks of limestone, many of which are 20 feet in diameter. The finer material is also angular, and therefore was not carried underneath the glacier, where it would have suffered much wear, but was superglacial débris. This moraine ranges in width from 200 to 300 yards. It is concentric in form, with the convex curve downstream. The angular material reaches a height of 200 feet above the stream on the west slope of the canyon and a much greater height on the east slope. The limestone from which it was procured outcrops a quarter of a mile upstream from the moraine. On the east wall of the canyon the limestone outcrop appears as a bold escarpment rising 1,000 feet above the stream. The striking thing about this outcrop is that it has recently lost all its loose material and been smoothed off. The present details and minor accumulations of talus may all have been developed since the last melting of ice from the canyon. Downstream from this angular moraine there is some stream wash which seems to have come from the margin of the ice when it was depositing the angular moraine. This wash has not assumed the form of a distinct valley train, but is spread out over the valley bottom for about a quarter of a mile beyond the moraine. The moraine of angular material is interpreted as a recessional moraine of the last epoch. It stands at an altitude of 9,700 feet.

The upper portion of the canyon is well cleaned out, bare rock surfaces are common, and the amount of postglacial work which has been done is insignificant. The single basin at the

head of the canyon is mostly above 11,000 feet. It is located just north of Tokewanna Peak and is surrounded by precipitous walls rising over a thousand feet above the floor. At least five small lakes yet remain in the basin. The ice in Middle Fork was about 500 feet thick in the basin and fully 700 feet thick in the canyon. During the later epoch the Middle Fork glacier was a little over 8 miles long, reaching its maximum extension at the 9,100-foot elevation.

EAST FORK OF BLACKS FORK (BASINS 42 TO 44).

About 2½ miles upstream from the junction of East Fork with the main stream the valley train terraces end and the terminal moraine of the later ice advance crosses the valley. The elevation at this moraine is about 9,100 feet. The moraine consists of drift ridges that advance from both sides of the valley to points within a few rods of the stream. The postglacial cut through the moraine is a sharp V-shaped gorge.

Upstream from the terminal moraine the valley is symmetrically U-shaped, with lateral moraine deposits on the slopes. A series of meadows separated by slight morainic deposits occupies the bottom of the valley. Two miles above the terminal moraine distinct recessional ridges protrude into the valley, indicating a considerable halt in the final retreat of the ice.

At the forks in East Fork there is a pronounced medial moraine extending as a ridge of decreasing elevation for 1½ miles down the valley. The upstream termination of this medial moraine, which is really the beginning of the moraine, stands 900 feet above the stream. As this morainic material must have been lowered somewhat when deposited by the ice, and since it has lost some by postglacial erosion, the present elevation of the crest above the stream beds does not represent the full thickness of ice in the valley at this point. It is probably safe to say that the ice that moved northward from basins 43 and 44 was at least 1,000 feet thick when it passed the upper limit of this medial moraine. This ice, a thousand feet thick at this point, pushed 5 miles farther downstream during the later ice epoch.

The right fork of East Fork, heading in basin 43, flows through a broad U-shaped canyon containing very characteristic glacial deposits. The lateral moraines are conspicuous ridges banked against the canyon walls up to elevations of 700 to 800 feet above the stream. At places above the drift deposits the bare rock walls record the upper limit of ice at points 300 to 500 feet higher than the present moraines. On the west wall of the canyon, 3½ miles above the fork and about 5 miles from the head of the basin, the upper limit of glaciation was definitely determined at 11,000 feet. The moraines in the valley, which continue to be very heavy to the lower margin of the catchment basin, are clothed with a dense pine forest, which obscures the details of the topography.

The collecting area is about 3 miles wide and 2½ miles long. The greater part of this basin is above 10,500 feet, and the upper limit of ice work recorded at the base of the precipitous bounding walls is in general at 11,500 feet, but at places is 200 to 300 feet higher. These facts indicate a thickness of ice in the basin of about 1,000 feet. About 1 mile below the head of the basin a belt of hummocky drift deposits occurs, and between the main lobes of the collecting area there are slight medial moraines. Aside from these deposits the basin floor has broad, flat, rock surfaces, which have been stripped of all loose débris. A few small lakes are located among the drift deposits of the basin.

The left fork of East Fork, heading in basin 44, flows through a narrow canyon, which has less material in its bottom than the adjoining canyon to the west. In further contrast to the right fork, this fork contains a series of recessional ridges which advance part way into the valley on either side, the complementary ridges being apparently parted by postglacial erosion. The valley bottom between these ridges is now meadow land, which may well have been the site of a chain of lakes held in by morainic dams.

The basin (No. 44) is well protected by precipitous walls that rise 500 to 1,000 feet above the basin floor. Heavy morainic deposits having a hummocky topography are lodged at the lower margin of the basin, 1½ miles below its head.

On the west wall of this canyon, just below the basin, there is a rock ledge or shoulder a quarter of a mile wide and 800 feet above the stream, which has been so cleaned off by the

ice that as yet little vegetation has found a footing there. On its surface there are two rock basin lakes. On another shelf on the same side of the canyon, 300 feet higher, there is a third lake. The upper limit of ice action is at least 300 feet still higher.

The materials constituting the entire system of moraines associated with Blacks Fork are just such as appear in the other valleys in this region. The greater number of the bowlders are of quartzite. Sandstones, limestones, and grits occur, and the fine material is such as arises from the disintegration of such rocks.

The basis for the discrimination of distinct epochs of glaciation is similar to that already stated in connection with the description of several of the valleys of the north slope and notably in connection with that of the valley of Bear River. The conditions here may be summed up briefly as follows:

1. Downstream from certain drift deposits, which have the form of terminal moraines and occur in each of the tributary canyons, the drift is much older in appearance than that upstream from these terminal moraines. The greater age of the lower drift is shown by its greater amount of erosion and weathering. The amount of postglacial work done in the outer drift is noticeable both in the number and size of erosion lines and in the thickness of soils.

2. About 6 miles downstream from the younger terminal moraines there are remnants of another terminal-like moraine. This terminal-like moraine once crossed the valley, but has since been partly removed by erosion.

3. Still farther downstream lateral moraine remnants lie on the valley slopes.

4. Extending downstream from the younger terminal moraines in the different forks and also from the outer terminal-like moraine there are distinct valley train terraces.

5. Up the canyon from the younger terminal moraines there are no distinct alluvial terraces.

It seems clear that there is at least a twofold division of the drift deposits associated with this system of glaciers, and possibly a threefold division. The younger terminal moraines seem to mark the extreme position of the ice during the last epoch. The outer terminal-like moraine may represent the extreme position during the earlier epoch, while the outermost lateral moraines may belong to a still earlier epoch. Another interpretation would be that the outer terminal-like moraine is a recessional moraine of the earlier ice. Between these two interpretations it is difficult to choose. The best reason for believing that a long time elapsed between the deposition of the outer lateral moraines and the outer terminal-like moraine is that the terminal moraine once associated with the outermost laterals is wanting and its place is occupied by alluvial deposits washed from the outermost terminal-like moraine now remaining. Possibly the earlier terminal moraine was in part carried away by waters issuing from the ice during retreat and in part buried by alluvium washed from the end of the glaciers when the valley train was developed and the terminal-like moraine was deposited.

The interest in this problem grows as the larger canyons of the Uintas are studied, for several of them show similar conditions. Most of the canyons on the south slope of the range contain lateral moraines that extend out beyond the frontal moraine from which the great valley trains were developed, and yet these frontal, terminal-like moraines are not the work of the last ice in the region. Perhaps the earlier epoch was marked by a great advance down the main canyons, followed by a retreat in each case to a less extended position, where the ice halted long enough to build up heavy moraines and to furnish alluvium for the chief valley trains in the region.

EAST FORK OF SMITH FORK (BASINS 45 AND 46).

The main basin (No. 45) of East Fork of Smith Fork canyon is in the central portion of the range, near the western margin of the Gilbert Peak quadrangle. The canyon of Smith Fork extends from the crest of the range a little east of north for 23 miles and retains throughout its course a remarkably uniform width of approximately 2 miles. In this distance of 23 miles the canyon has no large tributaries, and its bounding walls are almost unbroken.

During the earlier epoch of glaciation the ice moved down this long, narrow trough for nearly 20 miles. The outermost moraines stand a short distance upstream from the junction

of the East and West forks of Smith Fork, at a point nearly 4 miles north of the Gilbert Peak quadrangle. The central portion of the outer terminal moraine has either been entirely washed away or buried by alluvium. The remnants of this outer terminal moraine project into the valley on either side as parts of a once continuous crescent-like belt crossing the valley. These moraines have a hummocky knob-and-kettle topography. Terrace remnants of a valley train extend for several miles downstream from the remaining portions of the outermost moraine.

The terminal moraine remnants grade into lateral moraines on the sides of the valley, and between these lateral moraines there is another set of alluvial terraces. These terraces extend upstream to a much younger terminal moraine, where they end abruptly. The inner terraces appear to be portions of a valley train that was developed while the ice edge stood at the position of the younger terminal moraine. The distance between the outer terminal moraine remnants and the inner or younger terminal moraine is nearly 2 miles. The younger terminal moraine extends entirely across the valley except where a narrow V-shaped gorge has been cut by the stream in postglacial times. This moraine has a hummocky topography, with knobs and kettles. Lakelets, ponds, and swamps are numerous throughout the younger morainic belt. For fully 6 miles up the valley the drift deposits are so exceedingly heavy that it is impracticable within that distance to draw an inner limit for the terminal moraine. Above that point the quantity of drift in the valley bottom is notably less and the extent of the meadow lands is notably greater. Morainic hills and ridges are, however, scattered about on the valley floor even to the lower margin of the basin. The valley of Smith Fork below the catchment area is characterized by meadows and morainic belts, even down to the terminal moraine of the later epoch of glaciation. The stream meanders slowly through the meadows and hurries over bowlder beds in the morainic belts, where it is still cutting down its course.

On the valley slopes heavy lateral moraine ridges continue to a point within 2 or 3 miles of the crest of the range. These lateral moraines are at places within 100 feet of the uplands bordering the valley, indicating that ice must have very nearly if not quite filled the gorge during the period of maximum extension.

The catchment area consists of two large basins separated by a high rock ridge, at the northern end of which is a conspicuous rock known as Red Castle. Extending down the main canyon for 2 miles below Red Castle there is a massive medial moraine in which there are several small lakes. In the basin the ice work is recorded to an elevation of 11,700 feet, and as vigorous action is shown at this elevation it is certain that a considerable thickness of ice rose above that level. Rock basins were gouged out of the quartzite rock at the upper margins of the cirques, indicating powerful erosion at the very beginning of the movement. For the most part the floor of the basin has been swept clean by the ice, and little or no loose material is found there.

At the base of the precipitous bounding wall of the catchment basin there are talus cones of angular blocks which have fallen since the ice last melted away. These talus accumulations presumably cover the upper limit of glacial markings. In the catchment area there are at least seven lakes in rock basins and as many more in drift basins.

Basin 46 contributed a small glacier to the main valley. This tributary glacier was scarcely more than a mile long, but the stream from the basin now flows much farther before joining Smith Fork. In its course this stream descends abruptly nearly 400 feet at the margin of the main valley.

In constitution the glacial drift in East Fork of Smith Fork is chiefly quartzite and quartzite residual. The outer and older moraines are more deeply eroded than the younger, although the amount of weathering that the quartzite bowlders have suffered in the deposits of the two epochs is not noticeably different. The younger moraines are, however, so poorly drained that they are in this respect sharply differentiated from the older drift deposits. Even the main gorge is insignificant in a canyon so great, being but a few rods wide at the top and at places no wider than the stream at the bottom. In depth it varies with the dimensions of the morainic dams through which it is cutting, but is not more than 100 feet deep at any point.

HENRYS FORK (BASINS 47, 48, AND 49).

The first large canyon east of Smith Fork is that of Henrys Fork. The catchment basin lies just north of the crest line of the range and is separated from the neighboring basins by narrow divides. To the east of the basin Gilbert Peak rises to an elevation of 13,421 feet; to the south stands Wilson Peak, at 13,258 feet, and at other points on the rim three unnamed peaks rise to elevations above 13,000 feet. The maximum width of this catchment basin is 3 miles, and its area is between 6 and 7 square miles.

The canyon trends a little east of north and extends with abrupt bounding walls for at least 15 miles. At one point on the east side of the canyon the bounding wall is interrupted by a tributary gorge. In the lower part of the canyon, where it crosses the upturned beds on the flanks of the mountains, there is a narrow gateway through the hogback ridges of the foot hills. North of the gateway the valley of Henrys Fork is cut in Tertiary beds and has a broader, more open form than in the mountains.

The lowest signs of ice work in this gorge are found near the north border of Gilbert Peak quadrangle, at a distance of 15 miles from the crest of the range. At this point lie the remnants of a series of older or outer moraines, associated with extensive outwash. The older, outer moraines are at places hummocky and some of the depressions now contain swamps or ponds, the representatives of once larger morainic lakes. The remnants of the terminal moraine grade into lateral moraines that continue up the valley.

Between the outer lateral moraines there are alluvial deposits which appear at places as low terraces. This alluvium ends abruptly upstream at the lower margin of a younger terminal moraine. The relationship here indicates that the alluvium was derived from the glacial drift by the waters issuing from the glacier at the time the younger moraine was deposited. The distance between the two terminal moraines is fully 5 miles. The outer moraine stands at an elevation of 8,700 feet, and the inner one at an elevation of 9,400 feet. The outer moraines show somewhat more erosion than the inner and younger glacial deposits, but the contrasts are not so marked as would be expected in a region of greater rainfall. The weathering of the morainic material of the two epochs is not strongly contrasted in amount, but as the stones are so largely hard quartzite, this slight contrast is not surprising. Since the ice of the earlier epoch advanced fully 5 miles beyond the point where the last glacier stopped, it gathered some sandstones from the foothills.

The younger moraines form a heavy, hummocky deposit in the bottom of the valley for 5 miles upstream from the later terminal moraine. These deposits are especially heavy on the west side of the valley, and among them there are at least two large lakes, high above the stream bed. Nearer the basin region there are several more lakes in morainic basins, the whole number of such lakes in the younger drift deposits being at least seventeen. Most of these lakes are in the basin region. At the upper margin of the catchment area there are two rock basin lakes. The bounding walls of the area are precipitous in their upper parts and clothed with talus about the base. The upper portion of the basin is cleared of most loose material and the bare rock appears at the surface at short intervals.

WEST FORK OF BEAVER CREEK (BASINS 50 AND 51).

The canyon of the West Fork of Beaver Creek lies next east of the one occupied by Henrys Fork. It extends from the crest of the range to the northern margin of the mountains. At its head is Gilbert Peak, one of the highest points in the range, and at its northern terminus there is a well-defined gateway through the harder upturned layers along the north margin of the range. Throughout its length the canyon is a uniform U-shaped trough, receiving no large tributaries, varying but slightly from a mile in width, and ranging from a depth of 500 feet in the northern portion to 1,000 feet near the basin region. Below the catchment area the drift deposits in the canyon are clothed with a dense forest, which at places covers the slopes of the canyon and spreads over the surrounding country.

The outermost glacial moraines associated with this canyon lie a short distance north of the gateway. They are but remnants of a more complete system of deposits that were left by the ice of the earlier glacial epoch. The largest remnant lies west of the stream. The surface of this deposit is now gently rolling but contains undrained depressions which may once have held lakes. The material is of the same kind as that of the younger moraines. Most of the stones and bowlders are of quartzite, derived from the central portion of the range, but a few are of sandstone and limestone, gathered from the upturned beds near the margin of the range. The amount of postglacial weathering suffered by this older material appears to be little greater than that which the younger morainic material has undergone. The difference in weathering is not nearly so marked as in the rocks of the older and younger moraines among the Wasatch Mountains, where much of the material is crystalline. Even the Tertiary conglomerate, which is preglacial in age but composed largely of quartzite, has been very little weathered. Some of the bowlders in the Tertiary conglomerate and a few in the older drift deposits have been cracked; here and there large bowlders have been greatly reduced by shelling off, and about them lie the angular fragments which have fallen. The broken bowlders of the older drift emphasize the greater age of that formation, but the topographic differences, due to erosion and deposition, are more marked.

North of the chief remnant of this older moraine, at the mouth of the West Fork of Beaver, lies a body of alluvium so related to the moraines that it seems to have been formed as an outwash or morainic apron by the glacial waters. This deposit stretches about a mile to the northeast, to a point where it becomes associated with younger alluvial deposits which extend many miles downstream.

The younger alluvial deposits continue upstream to the margin of the younger moraines. They appear now as terraces bordering the stream and are so associated with the terminal moraines of the later epoch as to be interpreted as remnants of a valley train. It seems possible that downstream they may blend with the alluvial deposits made by waters associated with the earlier ice.

The terminal moraine of the last epoch is lodged in the gateway of the canyon, not more than half a mile from the upper limit of the older outer deposits. Between the two moraines lie alluvial deposits associated with the last epoch. At the margin of the younger terminal moraine there is a pronounced ridge, which rises 200 feet above the outwash and 10 to 40 feet above the general level of the hummocky region to the south. The hummocky area extends across the valley, contains numerous ponds and marshes, and in general appearance resembles the youngest system of moraines in the range. The stream has not yet succeeded in cutting through this terminal moraine, but is pounding away at the heavy bowlders, descending over a steep gradient to a relatively gentle slope in the open country to the north. The terminal moraine blends imperceptibly into what may be classed as lateral moraines, which mask the greater portion of the canyon for 5 miles above the gateway. Among these lateral deposits there are numerous small ponds and marshes.

Toward the basin region the canyon widens and its bounding walls become too steep to permit the lodgment of any large quantity of drift. Lateral moraines are absent in this portion, but over the floor of the basin there are irregular deposits of drift, classed as ground moraine. Among these deposits of ground moraine are several meadows, which are presumably old lake beds. The upper portion of the basin region contains a little drift and some talus. The talus at places appears to have been shoved a short distance from the base of the bounding cliffs by névé. Among the drift and névé deposits in the basin region there are at least six small lakes.

The catchment area is divided into two basins, Nos. 50 and 51, the former being by far the larger. The eastern or smaller basin shows distinct signs of enlargement by ice, although it is long and narrow in contrast to the broad, flat-bottomed basins at the heads of most of the glaciated canyons. The bounding walls of both basins are precipitous and are fringed at their bases by heavy accumulations of talus. The collecting area contains about 4 square miles. The thickness of ice in the basins was somewhat over 700 feet, and the lengths of the earlier

and later glaciers were 11 and 10 miles, respectively. The lower limits of these glaciers were at elevations of 8,900 and 8,600 feet, respectively.

From a point near the head of the canyon the entire course of the younger glacier may be seen. In such a view the position of the ice and the larger features of its work come out strongly. In the foreground are the cleaned-out or waste-swept basins, with their many lakes and meadows; farther down, in the open U-shaped canyon, are the heavy and densely forested moraines, which at a distance of 10 miles from the crest swing in to form a terminal moraine and complete the great lobe or tonguelike form of the ancient glacier.

MIDDLE FORK OF BEAVER CREEK (BASINS 52 TO 55).

The canyon of the Middle Fork of Beaver Creek is nearly parallel to that of the West Fork and of approximately the same length. At the head of the canyon there is a broad, open, amphitheatral area with four pronounced cirques grouped around the upper margin. Below this area the canyon is U-shaped in cross section, but its lower portion is heavily filled with drift. A dense forest now covers the morainic deposits and much of the bordering country to the east and west, obscuring the canyon form and making it very difficult to determine the exact extent of glaciation.

At the northern margin of the range the stream leaves the canyon through a narrow gateway and enters a broad, open valley. The canyon of the Middle Fork of Beaver Creek is a little less than 9 miles in length, yet it extends from the crest line to the northern base of the range. It is located where the crest line is relatively near the north margin, where the canyons of the north slope are short and the main canyons on the south slope are exceedingly long, measuring from 20 to 25 miles.

North of the gateway in the open country there are evidences of the earlier epoch of glaciation. They consist of morainic deposits and associated outwash. The earlier ice moved a little less than a mile beyond the upturned beds at the base of the range and remained there long enough to build up a very considerable morainic deposit and to furnish a vast amount of alluvium, which was spread out over the bordering country to the north. The elevation of these outer moraines is 8,500 feet.

The chief morainic remnant north of the gateway lies west of the stream. This deposit covers an area of about one-fourth of a square mile, and is probably not less than 100 feet thick. The topography of this moraine has been so softened in contour by weathering and erosion that it is gently rolling. Other portions of the older moraines border the stream south of the gateway and continue to the lower margin of a massive terminal moraine of the later epoch.

The outwash immediately associated with the older moraine appears as a terrace sloping gently away from the moraine. It is at least 75 feet thick at its upper margin, but becomes much thinner to the north. A single remnant of a high terrace occurring about 2 miles farther downstream has been interpreted as a portion of the outwash from the earlier glaciers.

Lying between the older lateral moraines and extending far out into the open country, as well as upstream to the margin of the younger terminal moraine, there are younger alluvial deposits, which are much less cut up by erosion than the older. Since the last glacial epoch the stream has cut but a narrow trench in this younger alluvium, but in the interglacial epoch great quantities of morainic material must have been removed and also large quantities of the older outwash material. The amount of erosion that has been accomplished since the last melting of ice is insignificant in comparison with that accomplished during the interglacial epoch. In interglacial time wide valleys were excavated; since the last epoch narrow trenches have been cut. It is fair to suppose that the country between Middle and West forks of Beaver Creek, north of the range, was covered by outwash from the earlier glaciers occupying these canyons, and that this outwash may have extended several miles northward. In this region large amounts of alluvium were removed by streams during interglacial time, and into the valleys of that period the alluvium from the later glaciers was washed. At many other points in the range there is similar evidence that the interglacial period was long, and while there are no data

for determining definitely its length, the impression gained in the field is that it was at least ten times as long as the period which has elapsed since the last melting of the ice.

The topography of the younger terminal moraine is extremely rough. Its surface is made up of knobs and kettles, and in many of the undrained depressions there are small ponds or marshes. This moraine can not be well differentiated from the lateral moraines, which are equally heavy and continue upstream for a little more than 5 miles. The moraines are heavily wooded, and all the information that can be gained in traveling up the canyon to the basin region is that there are vast quantities of drift lodged in the canyon; that the moraines have been but little modified by erosion since they were deposited, and that the main stream is yet working with great difficulty to cut its way through the glacial débris.

Toward the basin region the amount of drift in the canyon becomes less and less. The walls of the canyon become steeper upstream and at length rise precipitously above all glacial deposits. Where the canyon broadens out into the basin region irregular drift deposits, classed as ground moraine, inclose at least seven small lakes. In the upper cirque basins large areas of bare rock are exposed. The bounding walls rise 500 to 1,000 feet, and are bordered by a series of steep talus cones.

The extent of the catchment area is about 5 square miles. The thickness of the ice in the basin was not less than 700 feet and was probably much more. The lengths of the glaciers of the earlier and later epochs were 9 and 7 miles, respectively. As in the West Fork of Beaver Creek, the entire course of the glacier of the later epoch may be seen from an elevated position near the head of the canyon.

BURNT FORK CANYON (BASINS 56 TO 58).

Burnt Fork canyon is on the north slope of the range near the eastern margin of the Gilbert Peak quadrangle. The canyon extends from the crest of the range to the foothills, a distance of about 8 miles, in nearly a straight north-south line. Owing to a heavy filling of drift, which is overgrown by a dense forest, the canyon is not sharply defined. The forest is of magnificent proportions, extending from the snow-clad summits of the range to the foothills clothed with sagebrush and stretching east and west for many miles, over hills and valleys, and even into several of the larger canyons. It is possible to pass through the forest, along certain trails, without great difficulty, but the mapping of drift formations in detail in this portion would take an exceedingly long time. The basin region is peculiar in that it is a narrow area extending for about 7 miles along the northern margin of the crest line. It is bordered by several small cirques, bounded by precipitous walls.

To one advancing up the valley of Burnt Fork, the first positive evidence of glaciation appears about 2 miles below the gateway, in the form of isolated patches of morainic material lodged on the valley slopes. The coarser material in these moraines is quartzite and is strikingly conspicuous when found among the foothills of sandstones and limestones. This contrast is emphasized by the difference in color. The rocks of the foothills are light grays and buff with a small amount of bright red, while the quartzites from the central portion of the range are dark red and purple. The morainic patches are irregularly distributed over the valley slopes, most of them lying in rather protected places, where postglacial erosion could not readily attack them. Just below the gateway, west of the stream, a remnant of this outer morainic material nearly blocks a small tributary valley. At the downstream limit of these morainic patches, where the terminal moraine that was once associated with them must have lain, there are two patches of alluvium, which extend from the site of the terminal moraine northward. One of these patches, on the west slope of the valley, is directly associated with a morainic patch and the other is in the midst of the valley. This alluvium is composed largely of quartzite and is interpreted as outwash from the ice that built up the outer moraines. The material of the outer moraines and outwash shows as much weathering as any of the glacial deposits of the earlier epoch. The fact that these are but remnants and that they are located beyond a series of well-preserved moraines farther upstream is a more convincing argument of greater age than the difference in the surface weathering of the two sets of deposits.

In the valley between the outer morainic patches, 40 to 50 feet below the older alluvial deposits already described, there is a very persistent alluvial deposit, also largely of quartzite, which extends upstream to the lower margin of a massive terminal moraine in the gateway of the canyon. This alluvium is interpreted as an outwash or valley train of the later epoch of glaciation. The stream has entrenched its course 30 to 40 feet into this valley train, so that the deposit now appears as terraces bordering the stream for several miles below the gateway.

When the ice last left the canyon of Burnt Fork the younger terminal moraine must have blocked the gorge at the gateway. Since that time the stream has cut a narrow notch, fully 300 feet deep, near the west margin. The topography of this moraine is of the hummocky type, being made up of sharp knobs and kettles. In some of the kettle-like depressions there are small ponds or marshes. In general appearance and in the lack of erosion lines this moraine has the signs of extreme youth. It should certainly be classed with the youngest deposits in the range. Upstream from the younger terminal moraine at the gateway, through the dense forest belt, there are heavy morainic deposits with the characteristic hummocky topography. They mask the slopes and bottom of the canyon and continue upstream to the margin of the basin.

The lateral moraines in the main canyon have blocked a number of tributary streams, both on the east and on the west. On the west two streams that were blocked have worked their way out in postglacial time. On the east, just south of one of the big hogback ridges, there is a stream whose history has been somewhat unusual. The lower portion of its course is indicated on Pl. IV by a depression contour. The stream was blocked by the Burnt Fork glacier and by the east lateral moraines of that glacier. This valley received much wash from the margin of the ice and became in part filled with this alluvium. The ice, and afterwards the moraine, caused a ponding of the stream, but not sufficient to give the water of the lake a surface outlet. Some water may have seeped through the moraine, but the main outlet was at the bottom of the lake, near the limestone strata that form the hogback ridge. This underground outlet drained the waters of the lake, and the stream, following this course, has developed a valley in the alluvium fully 1 mile long, 40 to 50 feet deep at the lower end, and 100 to 200 feet wide at its mouth. The valley ends abruptly as in a great sink hole, and the stream now enters the limestone through an opening 10 feet wide and 5 feet high. All the material excavated in the development of the valley must have been carried away through this underground outlet. The point of exit of the stream from the limestone is not positively known, although a spring, comparable in size to the stream, issues on the north side of the hogback ridge at a point 700 feet below the place where the stream enters the rock. Other springs, farther east, are said to fluctuate with this stream, and as they lie along the strike of the limestone they may be outlets.

In the basin region of Burnt Fork the amount of drift is notably less than in the valley, although some irregular hillocks and mounds are scattered over the floor. Among these drift deposits there are at least twelve lakes. At many places about the margin of the collecting area bare rock surfaces are exposed. The walls around the basin rise at places 2,000 feet above the floor. They are steep, and yet, like those of other similar basins in the eastern portion of the range, they are largely covered by talus.

The whole catchment area may be roughly estimated to contain between 7 and 8 square miles. The thickness of ice was probably not less than 800 feet, and the length of the earlier and later glaciers was approximately 13 and 11 miles, respectively. The lower limit of the earlier ice was 8,100 feet, and of the later 8,800 feet.

WEST FORK OF SHEEP CREEK (BASIN 59).

The basin of West Fork of Sheep Creek is at the extreme eastern margin of the Gilbert Peak quadrangle. The canyon extends in a northeasterly direction from the Gilbert Peak quadrangle into the Marsh Peak quadrangle. The catchment area is surrounded by high, talus-clad walls, but these walls do not continue very far downstream. The canyon has more gentle side slopes and is more open than any of the main canyons of the range.

The glaciation of the West Fork of Sheep Creek is restricted to the upper 6 miles of its course, and throughout that portion, with the exception of the basin, the drift filling is heavy

and the forest covering luxuriant. The terminal moraine is a hummocky belt of topography containing several small lakes and marshes. The outer margin of the hummocky belt is clearly defined, being bordered by an open country of slight relief, overlain in part by outwash from the ice when it stood at its position of maximum extension. The inner margin of the terminal moraine belt is separated by a distance of about one-half mile from the outer margin and is rather well defined. Upstream from the terminal moraine there are heavy lateral moraines, each of which, for the greater part of its length, has a ridgelike form on the outer margin but a hummocky belt of topography immediately within.

In the midst of the valley there are deposits of drift with gentler topography, which have been classed as ground moraine. These ground moraine deposits contain many small basins in which there are lakes or marshes. The stream in this portion of its course crosses several areas of meadow land which may once have been covered by standing water. Below each meadow the stream has cut through a mass of moraine which may have served as a dam.

Toward the basin the forest growth becomes less dense, the amount of glacial drift decreases, and the area of bare rock becomes correspondingly greater. There are at least nine lakes in the basin region and at least eight more among the moraines farther downstream. The collecting area is divided by a projecting rock spur into two portions, each of which has been somewhat modified by ice. Each of these minor basins now contains a large quantity of angular talus material, some of which appears to have been moved by névé. Unlike many of the basins in the central portion of the range, the basin of West Fork of Sheep Creek contains no broad, flat areas from which the glacial waste has been swept.

From the rim of the basin a bird's-eye view may be obtained of the entire course of the glacier. The lateral moraines may be traced northeastward to their junction with the terminal moraine. The trough of the glacier is somewhat roughly defined through the forest-clad country and the symmetrical lobelike form of the ancient glacier may be seen.

No evidence of more than one epoch of glaciation was found in the valley. The drift deposits appear as young and fresh as any in the range and have therefore been classed with the later epoch. In this basin, as in several others in the range where distinct epochs have not been determined, the later ice may have advanced as far as any earlier ice and obliterated the older records. All the glacial drift was derived from the quartzite, as the ice did not move beyond the outcrop of that formation.

The size of the basin may be estimated at about 2 square miles. The thickness of ice in the basin was probably not less than 600 feet and the length of the glacier was about 6 miles. The width of the glacier was approximately 1 mile. The lower limit of the ice was not determined with accuracy, owing to the lack of a good map, but it is approximately 8,500 feet.

The crest line of the range at the head of West Fork of Sheep Creek has a beautifully scalloped outline (Pl. VIII, *A*), suggesting the forms left in dough by a circular biscuit cutter. The plucking by the ice at the heads of the cirques on the two slopes of the range has worked the cirque walls back until there is little left but the rock spurs which project northward and southward between the cirques on the respective slopes.

EAST FORK OF SHEEP CREEK (BASIN 60).

Next east of West Fork of Sheep Creek there is a small stream which may be called Middle Fork of Sheep Creek. This fork occupies a relatively small valley, which does not head at the crest line of the range and which was not glaciated. There are moraines adjoining this valley, but they are associated with the larger valleys to the east and west. Next to Middle Fork of Sheep Creek on the east is East Fork of Sheep Creek, which flows in approximately the same direction as Middle and West forks. This fork occupies a glaciated canyon. Its basin contains two large cirques and its canyon has the characteristic U-shaped form.

The outermost moraine is located near the place where the Government road[a] crosses Sheep Creek, at a distance of about 7 miles from the crest of the range. East of this moraine

[a] The Government road crosses the range near the eastern margin of glaciation and is a most convenient feature to refer to in locating certain of the glacial formations. (See Pl. IV.)

A. HEAD OF WEST FORK OF SHEEP CREEK.
Showing scalloped crest line of Uinta Range.

B. LAKES IN BASIN OF WHITE ROCKS CANYON.
Held by morainic dams.

there is considerable outwash material, which in part follows the course of the stream as a valley train and in part spreads out eastward as an outwash plain over a broad meadow land.

The outwash and terminal moraine material was derived entirely from the quartzite of the central portion of the range, for the ice, even at its maximum extension, did not advance beyond the outcrops of that formation. The terminal moraine has a pronounced ridge at its outer margin, but immediately within that ridge the topography becomes hummocky. The stream has cut its way through the terminal moraine at the northern margin and now flows between the morainic hills at the right and a hogback ridge of red quartzite at the left. The quartzite formation at this outcrop is a fine grit. The stream appears to have shifted laterally until it reached the hard rock outcrop, and since then its principal work has been to deepen its course. The depth of postglacial cutting through the moraine and associated alluvium is between 80 and 100 feet.

Upstream from the terminal moraine heavy lateral moraines are banked on either side of the valley and extend to the lower margin of the catchment basin. Toward the basin these lateral moraines gradually become higher and higher above the stream, starting at an elevation of about 100 feet at their downstream termini and reaching an elevation of fully 1,000 feet above the stream near the basin. On the valley bottom there are irregularly distributed deposits of ground moraine, among which lie numerous ponds and marshes. In the basin region the amount of drift is less, and bare rock is at many places exposed.

The bounding walls of the basin are steep, and yet not too steep to prevent large quantities of angular talus material from lodging on them. In the western portion of the basin a lake, held in by a low morainic ridge, occupies the greater portion of the floor of one of the minor cirques. The size of the basin may be fairly estimated at about 2 square miles. The thickness of ice in the catchment area was not less than 600 feet and in the canyon the glacier was at least 1,000 feet thick. At its maximum extension the ice reached 7½ miles from the crest of the range and descended to an elevation of 8,000 feet. No evidence was found of more than one epoch of glaciation in this valley. This may be due to the heavily forested condition of this portion of the range, and yet earlier records may have been obliterated by the later ice. This valley, like several others in the eastern portion of the range, is short and not a pronounced canyon like those in the central portion of the area. The ice was therefore not so effectively concentrated, nor were the alluvial deposits associated with the margin of the ice. Furthermore, the actual difference in the length of the two glaciers in these shorter valleys would have been less than in the longer valleys of the range. The hypothesis that the shorter valleys in the eastern portion of the range were glaciated during the earlier epoch and not during the later has been carefully considered in the field, but the freshness of the moraines, the insignificance of the postglacial erosion, and the numerous lakes and ponds, all forbid that interpretation. The evidence of the earlier epoch has either been obliterated or has not yet been found.

BEAVER CREEK SYSTEM (BASINS 61 TO 64).

The small streams east of East Fork of Sheep Creek and west of Kettle Creek are locally known as the headwaters of Beaver Creek, a tributary to Sheep Creek. These small streams head in the cirques just north of the crest of the range. There are no pronounced canyons associated with these cirques, but the streams find their way northward through heavy morainic deposits. These deposits extend between 5 and 6 miles north of the crest, and so completely mask the country as to indicate that the ice which formed there must have coalesced soon after leaving the catchment basins. With the exception of the cirques, the entire country covered by this ice is overgrown by a dense forest, in which there is a great abundance of fallen timber.

It is impracticable to map the moraines in detail. The outermost belt, or terminal moraine, may be reached from the Government road. Its topography is of the knob-and-kettle type and some of the depressions contain small lakes while in others there are swamps. The terminal moraine belt is from one-half to three-fourths of a mile wide and extends across the entire area in front of the basins. On the outer margin there are alluvial deposits in the form

of an outwash plain, fitting around certain low hills beyond the maximum position of the ice. On the inner side the terminal moraine grades into other morainic deposits which have been classed as ground moraine. The real beltlike form of the terminal moraine may be best made out from outlook points on the crest of the range. From these points lateral and medial moraines may also be discerned. At the east and west margins of the area there are lateral moraines, and a medial moraine extends from each of the rock spurs separating the different basins. These medial moraines are the topographic continuation of the rock spurs dividing the catchment area into distinct basins, and they extend northward from 1½ to 2 miles and then lose their identity in the general mass of morainic deposits. The three medial moraines divide the area covered by this system of glaciers into four troughs which, though poorly defined in the outer portion of the area, become more distinct near the basins. In their upper portions these troughs are U-shaped and less heavily loaded with drift.

The basins of this system of glaciers are all cirquelike. The bounding walls are precipitous and yield large quantities of angular talus material to the upper portions of the basins. The floors stand at a common elevation of about 10,000 feet, and the protecting walls rise to elevations of 11,500 to 12,000 feet.

The entire area covered by the Beaver Creek glaciers is within the quartzite area of the range, and the drift is therefore monotonously uniform.

Basin 64 is the easternmost basin on the north slope of the Uintas that is known to have furnished a glacier.

GLACIAL PHENOMENA OF THE CANYONS OF THE SOUTH SLOPE.

BASIN 65.

In a small basin east of Leidy Creek a glacier was generated which moved eastward and then turned slightly to the south, reaching a maximum length of a little over 5 miles. This glacier may almost be said to have been formed on the crest of the range, but it drained toward the south and the present drainage from basin 65 belongs to the south slope. The basin stands wholly above 10,000 feet and is well protected by bounding walls. The valley through which the ice moved is relatively wide and now contains heavy deposits of glacial drift overgrown by a dense forest.

The outer margin of the left or northern lateral is sharply defined. It lies less than 1 mile west of the Government road, and may be followed until it swings in toward the stream to join the corresponding lateral moraine on the other side of the valley and form a terminal moraine. The elevation of the terminal moraine as determined by an aneroid is 9,250 feet. The lateral moraines and the terminal moraine have a rough, hummocky topography. The left lateral moraine and the terminal moraine are bordered by outwash material composed, like the moraines, entirely of quartzite. No distinct evidence of more than one epoch of glaciation was found. From what was seen it would appear that the last ice that occupied the valley extended as far as any earlier ice which may have been there.

Upstream from the terminal moraine the inner margin of the lateral moraines is poorly defined, and yet there is a broad area of ground moraine in the central portion of the valley. In the ground moraine and in the lateral moraines there are many small lakes and ponds and scores of marshes.

Toward the basin the amount of drift becomes less and the density of the forest therefore decreases. Bare rock surfaces appear in the basin, although they are not so numerous as in the central portion of the range, where glaciation was more vigorous. There are two small lakes in the basin, held in by morainic dams. About the rim of the basin there is the usual abundance of talus material.

The ice that formed in basin 65 had an average thickness of about 500 feet. The maximum thickness of the glacier was 800 feet, and the length of the glacier was 5½ miles.

ASHLEY FORK (BASIN 66).

West of Leidy Peak and north of Marsh Peak there is a capacious catchment area which furnished a glacier that moved nearly 8 miles down the valley of Ashley Fork. The floor of this basin is above the 10,000-foot elevation and is protected by walls that rise, at places, over 2,000 feet higher. The canyon is U-shaped, but is decidedly clogged with drift in the lower portion of the glacier's course.

The outermost or lowest morainic deposit is located in a dense forest near the junction of the stream from basin 65 with Ashley Fork. This moraine consists of a hummocky belt that blends insensibly into the two lateral moraines, which extend for several miles upstream. The floor of the canyon, which becomes increasingly wider toward the basin, is masked by irregularly distributed deposits of ground moraine. Among these deposits there are numerous lakes and meadows, suggesting a great chain of lakes which formerly existed in the valley trough. Five large lakes yet remain in the upper portion of the canyon.

Some bare rock is exposed in the basin, but, as is common in basins in the eastern portion of the range, there are large quantities of talus. Even the bounding walls are largely covered by loose angular blocks. On the northeast slope of Marsh Peak there are three beautifully symmetrical cirques which furnished ice to the main glacier. These cirques are bounded by precipitous walls which are now furnishing talus material in large quantities. On the sides of the basin there are rock benches or shoulders, 500 feet or more above the stream. These benches have been glaciated and have probably been widened at their upper margins by the action of the ice. Their elevation above the stream is due, in part at least, to ice erosion along the main line of movement.

The collecting area may be roughly estimated at 5 square miles. The thickness of ice in the basin was about 900 feet. The length of the glacier was approximately 10 miles, and its lower limit was near the 9,000-foot elevation.

DRY CREEK TRIBUTARY OF ASHLEY (BASIN 67).

Dry Creek is the local name for the main West Fork of Ashley Fork. The upper portion of the canyon is west of Marsh Peak. The basin, an open amphitheatral area bounded by talus-clad walls, is located just south of the crest of the range and about 4 miles west of Leidy Peak. The upper portion of the canyon has the U-shaped form characteristic of glacial troughs. South and east of the lower limit of glaciation the canyon is bordered by rugged walls that rise 500 to 700 feet above the stream. Beautiful bizarre forms of weathering are found on these walls, and these features are in sharp contrast with those in the glaciated portion of the canyon, where all roughnesses have been removed and the canyon slopes are either smoothed off or masked by morainic deposits.

The outermost moraine in this canyon is 10 miles south of the head of the catchment basin, at an elevation of 9,000 feet. South of this moraine there is a valley train deposit, which reaches fully 2 miles farther downstream. This valley train deposit is but a few feet thick even at the margin of the moraine, and therefore postglacial intrenchment by the stream has not developed very conspicuous terraces. The terminal moraine is composed of massive drift ridges which to-day nearly close in across the valley. The material in the terminal moraine, and also in all of the moraines in this canyon, is made up of quartzite, sandstone, and grit. Some of the larger bowlders in the moraines range up to 13 feet in diameter and are extremely fresh in appearance. The well-preserved condition of the bowlders is in harmony with the general freshness of the morainic forms. Aside from the narrow gorge cut by the main stream, these moraines have suffered very little erosion.

The outermost morainic deposits in this canyon seem to belong to the last glacial epoch. It is possible that the later ice advanced as far down the canyon as did the earlier and obliterated all records of earlier ice. No positive evidence was found for subdividing the deposits. Upstream

from the terminal moraine there are lateral moraines which continue to the lower margin of the basin, and on the floor of the canyon there are ground moraine deposits. The drift deposits in the canyon are heavily clothed with forests and the details of topography are thus hidden from view.

The basin of Dry Creek contains about 4 square miles. It is fairly well swept of loose material and bounded by slopes that are less precipitous than those of most of the basins farther west in the range. The basin walls are masked with heavy talus blocks, which at places extend from the floor to the very crests of the divides. Slopes of this type are characteristic of the eastern portion of the range and one is shown on Pl. III, *A*. Among the deposits in the basin region of this canyon there are at least five small lakes. The thickness of ice near the beginning of movement was probably not less than 1,000 feet.

WHITE ROCKS CANYON (BASINS 68 TO 74).

The basin or basins of White Rocks Canyon are located in part in the Gilbert Peak quadrangle and in part in the Marsh Peak quadrangle. The canyon trends southward for 10 miles from the crest of the range, then turns southeastward for 6 miles, and after another turn of 2 miles to the south reaches the margin of the range. The canyon opens through a narrow gateway out upon the terraced lowlands south of the mountains.

Within the gateway, at an elevation of about 6,600 feet, three or four low morainic ridges descend the valley side on the east and swing across the valley to the west side, where the stream has cut a deep postglacial gorge. The morainic ridges in the center of the valley rise scarcely more than 10 to 15 feet above the stratified drift about them. Bowlders 5 to 6 feet in diameter are not uncommon in these ridges, and some much larger, even to 12 feet in diameter, are present. Planation surfaces are well preserved on much of this larger material. The morainic ridges farther north occur at slightly lower levels, successively, so that the stratified drift between them slopes gently northward. The belt crossed by these morainic ridges is approximately a mile wide. South of the drift ridges there is a well-marked valley train, represented by a series of terraces, which are best shown on the east side of the river. A few miles downstream the valley train blends with the present flood plain of the creek.

Owing to the steepness of the rock ledges in the gateway of the canyon, morainic material occurs only on the lower slopes of the valley walls near the point where the ice lobe terminated and at the mouths of two large ravines, one on each side, a mile or more up canyon. Here morainic material is lodged several hundred feet above the present valley bottom.

Upstream from the outer terminal moraine belt, with its associated stratified drift, the bottom of the canyon is so much lower that the terminal moraine filling in the valley must be at least 150 feet thick. For several miles northward the sides of the valley are masked by large fans of angular material. One of the fans has a radius of half a mile and forces the stream against the west side of the valley. Large talus slopes of very coarse material lie at the foot of steep cliffs, and sharp V-shaped valleys appear on the valley sides above the fans. Since it is hardly conceivable that the ice could have passed down the valley without destroying these features, had they been in existence in preglacial time, we must admit that a period sufficiently long to permit the development of the fans has elapsed since the formation of the outer moraines.

Four miles above the outer moraines, at a stream elevation of about 7,250 feet, just above the large tributary valley entering from the northeast, an exceedingly massive moraine descends on the east side and almost blocks the valley. From one of the high knolls the corresponding lateral moraine can be traced for several miles up the valley on the west side to an elevation of about 10,000 feet. In the canyon above this terminal moraine belt there are no large alluvial fans. The morainic deposits are less eroded than those farther downstream, and the general appearance of this portion of the canyon indicates that it was much more recently occupied by ice than the portion farther downstream. Alluvial outwash from the younger terminal moraine is very scant in this canyon, but this is in accord with the data noted in many of the canyons of the south slope.

About 2½ miles upstream from the younger terminal moraine is the lower end of an inner rock gorge. Above this inner gorge the canyon walls have in places been swept clean of loose material by the ice, but the more gentle slopes are masked with morainic deposits. Farther upstream the main canyon opens again, the inner rock gorge ends, and the floor is covered with more massive morainic deposits. The deposits in the upper part of the canyon consist chiefly of ground moraine. A few medial moraines continue downstream from certain rock spurs which subdivide the basin. Near the upper margin of the catchment area drift is very scarce, but talus accumulations are abundant. At points about the margin of the basin talus terraces appear. These terraces in places attain a width of 300 feet and a length of many rods. They were probably not formed entirely from material that fell directly from the cliff above, but apparently originated in some other way. It may be that the material in the outer portion descended across snow banks at the base of the cliffs, or, becoming lodged upon such snow banks, was dropped in its present position on the melting of the snows. Such terraces appear in several other basins in the range. The ground moraine in the basin formerly contained many lakes, but all these lakes have been drained except nine or ten near the headwaters of the stream. (See Pl. VIII, *B*.)

The catchment area of the White Rocks glacier may be considered to include all the territory covered by ice at the head of the canyon, north of the forking in the stream, where the canyon begins to broaden. This area contains between 20 and 25 square miles and is therefore much larger than the collecting ground of any other single glacier that has thus far been considered. It is one of several immense catchment areas on the south slope of the range. These basins are in the central portion of the great anticlinal arch, where the beds are approximately horizontal and the structural conditions have favored the development of very broad basins. When the glacier ice first formed at the heads of the preglacial canyons, plucking, at the margin of the ice, at the base of the bergschrund,[a] went on under most favorable conditions. The horizontal beds of different hardness yielded to the action of the ice at the very beginning of motion and the bounding walls began to recede. The carrying away of the material at the base caused the receding wall to assume and retain a precipitous face. This work went on, broadening the basins and consequently narrowing the intervening areas, until in many places only narrow knife-edge divides were left above the ice. (See Pl. II, *A*.) Most of these narrow divides were presumably covered by snow and some of them were removed and continuous ice sheets were formed above them. At places the broadening went on at certain fixed horizons, and extensive areas of a single rock stratum are exposed. At many places in these immense basins one resistant stratum served as a base to which the work of excavation went on, and then there was a sudden drop of 10 to even 100 feet to another horizon, at which another broad flat bench or platform was developed. Many of these features are best shown in the Hayden Peak quadrangle, although they occur at several places in the series of larger basins on the south slope.

The White Rocks catchment area is divided into two large basins, each of which is subdivided into several minor basins separated from each other by narrow spurs which have not been glaciated. These basins are located just south of the main crest line of the range, with high bounding walls favorable for catching and retaining vast amounts of snow. The upper limit of glacial phenomena in these basins is at many places as high as 11,000 feet, but at a few localities ice action is recorded nearly up to 11,500 feet. The portion of the mountains that rose above the ice in this region was insignificant and was in the form of narrow ridges, many of them less than 500 feet above the ice, and presumably much less appeared above the snow fields of the glacial period. The action of the ice does not seem to have been as vigorous in these basins as in the more central portion of the range. The bed rock appears at the surface at but few places, and these exposures are not nearly so large as those in the basins farther west. The morainic deposits in these basins are, however, more massive than those in the central basins of the range. The ice in the basin was certainly more than 500 feet thick, and in the canyon below the basin it reached a thickness of at least 1,500 feet. The later glacier was 16 miles long and reached its maximum extension at about 7,250 feet. The earlier glacier was nearly 20 miles long and descended to an elevation of 6,600 feet.

[a] Johnson, W. D., Jour. Geology, vol. 12, p. 573; Gilbert, G. K., Jour. Geology, vol. 12, p. 582.

UINTA CANYON (BASINS 75 TO 86).

The largest catchment area in the entire range which was tributary to a single glacier is found in the central portion of the Gilbert Peak quadrangle, on the south side of the crest line at the head of Uinta Canyon. The main basin is a broad, open region, with comparatively slight relief. Through this basin several headwater streams wander from lake to lake or meadow to meadow, collecting the waters from melting snow and infrequent rains. At the lower margin of the main basin these headwater tributaries enter as one stream into a sharply incised river gorge in the bottom of the broad Uinta Canyon. This inner gorge becomes deeper and deeper for the first 4 miles, to a point where it reaches a maximum depth of 100 feet, and then decreases in depth more rapidly than it increased, dying out in another 2 miles. The sharp inner gorge of the main canyon is therefore about 6 miles long.

In the tributary canyons entering from the west, inner gorges have also been developed headward for distances reaching up to 3 miles. If these inner gorges be neglected, the main canyon of Uinta River and the tributary canyons from the west have broad U-shaped forms. On the east of the main canyon there are three tributary basins, Nos. 75, 76, and 77, which also furnished ice to the main Uinta Canyon glacier. The main canyon, measured from the head of basin 79, is a little over 20 miles long. The larger tributaries from the west heading in basins 83 and 84 are each about 7 miles long.

In agreement with the large catchment area and the large tributary basins, the glacier that descended the Uinta Canyon was the longest in the range. During the earlier and more extensive epoch of glaciation the ice from Uinta Canyon moved beyond the foothills at the south margin of the range out onto the terraced plains of the lower country. When the ice reached the lower country it deployed somewhat widely to the west, but nevertheless reached its greatest extension in the valley. The maximum length of this earlier glacier, measured from the head of basin 81, was 27¾ miles. The length of the later glacier was 20 miles. At the outermost position of the ice in the valley there are to-day morainic deposits so nearly buried by alluvium that they appear as low ridges rising 10 to 20 feet above their surroundings. The alluvium is valley train material which begins a short distance upstream from the terminal moraine ridge and continues for several miles downstream beyond the southernmost point reached by the ice. The valley train has been partially removed and the remaining portions appear as stream terraces. West of the main channel, and therefore bordering the foothills, there is a belt of massive morainic hills, which marks the position of the lobe of ice that deployed westward from the main canyon as soon as it reached the margin of the range. These morainic hills rise over 1,000 feet above the present stream bed, and if their entire height is due to the thickness of the terminal moraine at this point, the deposits are as massive as any in the range. It is, however, possible and probable that the ice of this westward lobe moved over a considerable thickness of the Tertiary deposits bordering the mountains and left these moraines on a surface that stood somewhat above the level of the present stream bed; yet no exposures were found which would indicate that the 1,000 feet from the crest of the moraine to the stream bed were not made up entirely of drift. Fig. 4 is a diagrammatic cross section of the Uinta Valley near the south edge of the foothills. The moraines of this western lobe rise 300 to 400 feet above the bordering country to the south, indicating at least a very considerable thickness of drift.

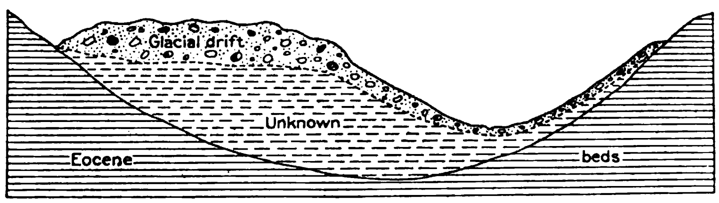


FIG. 4.—Diagrammatic cross section of the Uinta Valley near the foothills. The portion marked "unknown" may be composed of Eocene deposits or of glacial drift.

South of the massive morainic hills west of the main valley there is a morainic apron. This morainic apron or outwash is composed of glacial gravels and bowlders, many of the latter reaching 2 feet in diameter. The outwash has a very steep gradient, not only southward but radially westward. A mile or more south of the moraines there is a small mesa which is composed of Tertiary beds and preserves at its surface the normal dip of the Tertiary formations.

Here the difference between the dip of the Tertiary formations and the surface slope of the glacial outwash comes out distinctly. The outwash plain has a much steeper gradient than the mesa. A deep channel which heads in the moraine crosses this outwash and extends west of the main valley. This channel is not now occupied by a permanent stream and may have been developed by waters issuing from the glacier.

The land north of the outermost terminal moraine ridges in the main valley slopes gently northward in the form of an ill-defined gravel plain, which is interpreted to represent the filling in front of the ice and behind the moraine as the ice edge receded. The valley is broad and is characterized by extensive alluvial fans. On the side slopes of this portion of the canyon there are heavy morainic deposits which have been mapped as lateral moraines. These deposits are somewhat interrupted by erosion lines, yet their ridgelike character is still noticeable. The deposits in the valley bottom have been classed as ground moraine, although they are in part masked by postglacial alluvium washed from the sides.

Nine miles upstream from the outermost position of the earlier glacier there are younger moraines which descend the valley slopes and swing inward, in the manner of terminal moraines. These moraines mark the maximum position of the later glacier. Uinta River has cut a broad passageway through this younger terminal moraine, but the spurs on the sides continue up the valley slopes and blend into a pair of lateral moraines, lower than the pair which continues farther downstream. Above the younger terminal moraine travel upstream is extremely difficult. The moraine deposits are heavier and are less softened by erosion than the older deposits, and the amount of alluvium washed from the sides is insignificant in comparison with that downstream from this moraine. A short distance upstream from the younger terminal moraine the inner rock gorge begins, and the side slopes become extremely rugged for several hundred feet above the stream and for several miles up the canyon. The canyon walls are masked by fresh angular talus, over which it is impracticable to take horses. The east wall is too steep for the lodgment of much drift, and consequently too steep for travel. The west wall is broken by several large tributaries, each of which has its own inner rock gorge that must be avoided. The route up the canyon is therefore extremely circuitous and keeps one in dense forests, where a more secure footing may be found. From prospective points, however, the great U-shaped canyon of the Uinta may be seen, and marks of glaciation recorded 2,000 feet above the canyon bottom stand out clearly. Below the upper line of ice action the canyon wall has been notably smoothed. No fantastic features remain, and even the small valleys which may have existed on the side of the main canyon have been obliterated. The ice seems to have greatly broadened the canyon as well as deepened it. Above the upper line of ice action the features are bold and rugged. Small tributary canyons remain, but as "hanging valleys."

Every tributary canyon or basin along the course contributed to the great Uinta Canyon glacier. In basin 75 a small tributary glacier formed, which moved westward for a little more than 3 miles before reaching the main glacier. The bed of this glacier is asymmetrical. It is located along the strike of beds which dip notably to the south, and the stream has shifted in that direction. The ice must also have been influenced by these structural conditions and may have emphasized the asymmetry of the gorge. To-day this tributary is heavily clothed with timber, except in the upper portion or basin region and on the steep south slope. The basins on the east, 76 and 77, are beautiful cirques, cleaned of all loose material save a little of post-glacial age lodged at the foot of steep slopes. The tributaries from the west, 82 to 86, inclusive, each contained a considerable glacier. The ice that formed in basin 86 moved independently for 3 miles before joining the glacier of the main canyon. In that stretch its maximum thickness was about 500 feet. The course of this glacier is so overgrown by a dense forest that it is impossible to obtain any accurate knowledge as to the arrangement of moraines. It is safe to assume, however, from the heavy forest growth, that morainal deposits mask the greater part of the course. Near the head of the canyon in the catchment region there are at least three small lakes. The tributary canyon heading in basin 85 presents no glacial features notably different from those of the tributary just described. Its entire course is heavily clothed with timber. The glacier which originated here was, at its beginning, 4 miles from the main canyon,

and the position of the lateral moraine on the north slope of the tributary valley indicates that the ice must have been 700 to 1,000 feet thick. The canyon is asymmetrical in form, and the steep wall to the south retains little or no glacial débris.

Basin 84 is as large as many of the catchment areas which gave rise to the main glaciers on the north slope of the range, but the ice from this basin was contributed to the glacier of Uinta Canyon. This basin is at the southeast base of Mount Emmons (altitude, 13,428 feet), one of the highest peaks in the range. It is bounded by talus-clad walls, at the base of which there is evidence of some postglacial névé work. The upper portion of the basin is well cleaned out and bare rock is exposed at many places. Farther down the course heavy moraines characterize the topography, and among these moraines there are at least seven lakes. The moraines are heavily clothed with timber, but their general position and the position of the great medial moraine at the mouth of the tributary may be seen from the summit of Mount Emmons and other high points on the bordering divides. The moraines are of the hummocky type and the morainic material is uniformly and exclusively quartzite.

Basin 83 contains 6 to 8 square miles which may be considered as belonging to the catchment area, and the ice which formed here moved 4 to 6 miles before joining the main glacier of Uinta Canyon. The maximum distance moved by any of the tributary ice before joining the main glacier was from the westernmost portion of the basin to the border of the main canyon, a distance of 8 miles. The basin is bounded by talus-clad divides except in its northwestern part, where the ice of this basin was joined to that in basin 81. This part of the rim is not so high as the rest, and the loose material here has been largely removed. There was no vigorous ice action over the divide, for on either side the movement was away from it, and the upper limit of ice action in the neighboring basins is at about the same height as this portion of the divide. This basin is remarkable for the abundance of drift throughout the greater part of its length and for the numerous lakes, seventeen in number, most of which are among the drift deposits. One of these drift basin lakes is among the largest found in the range, being 1¼ miles long and a quarter of a mile wide. At the western border of the basin, on a rock terrace in which the ice gouged out depressions, there are a few small lakes. The morainic deposits which mask the floor and the lower slopes of this tributary canyon have a hummocky topography, but higher on the slopes and at the mouth of the gorge the glacial deposits assume distinct ridgelike forms. Where the tributary ice joined the glacier of the main canyon a massive medial moraine was formed. This medial moraine is not a single ridge, but consists of a number of low and somewhat parallel ridges, extending from the main or highest ridge and ending in spurs that turn to the tributary canyon. These lower ridges are believed to represent stages in the melting of the ice. The morainic material is entirely of quartzite or quartzite residual, for that is the only rock available in the tributary canyon.

The tributary canyon heading in basin 82 furnished a small glacier, which added its ice to that in the main canyon. This small glacier had a maximum length of 3 miles, and its course is masked by heavy drift deposits which it carried. These deposits give a rough or hummocky topography to the bottom of the course, but soften the side slopes as far up as they are lodged. At the junction of this canyon with the main canyon a distinct medial moraine appears. One glacial lake was noted in this canyon, but the heavily forested condition may have obscured others.

The undescribed portion of the Uinta system, including basins 78 to 81, inclusive, may well be considered as belonging to the main catchment area. This area is of irregular outline and is partially subdivided by a number of sharp spurs which project into it from 1 to 3 miles. These sharp spurs define a number of distinct cirques which were immediately tributary to the immense ice field where the Uinta Canyon glacier originated. The maximum east-west dimension of the catchment area is 13 miles and the maximum north-south dimension is nearly 4 miles. Making allowance for the rock spurs which rose above the ice fields, this catchment area contains fully 30 square miles. The size of the Uinta catchment area as thus defined is greater than that of any other catchment area in the range, which is appropriate for the longest glacier in the range. The number and size of the tributary glaciers in the Uinta system were,

however, important factors in determining the length of the main glacier. The floor of the Uinta catchment area has, throughout its greater portion, a drift topography. At places this topography is rolling, with broad, shallow depressions surrounded by hills of gentle contour, while at other places steeper hills and kettle-like depressions dominate. Great morainic ridges advance far into the basin from the termini of the rock spurs separating the different tributary cirques.

On the whole, this catchment area is not so well cleaned out as most of those farther west in the range, and the irregular distribution of the heavy drift deposits within it has given rise to numerous basins where lakes now exist or where meadows and swamps record their former presence. Twenty-seven lakes have been mapped in this catchment area, and of these two are known to be in rock basins. The number of meadows and swamps within the area is several times the number of lakes. A crescent-shaped lake at the east border of the basin is an interesting example of a lake held in against a cliff by a lateral moraine. At a few places near the base of the bounding walls of basin 78 bare rock is exposed and polishings and striation are shown. The walls of the basin are talus clad and have much less rugged forms than those farther west. They belong more to the type characteristic of the eastern portion of the range, where the rock is less resistant and has given rise to fewer cliffs, but has developed wonderful talus slopes. The drift throughout the catchment area in all the tributary canyons and cirques that furnished ice and in the main canyon, even beyond the terminal moraine of the later glacial epoch, is necessarily composed entirely of quartzite, for the ice of the later epoch did not move beyond the outcrop of the central quartzite area. The earlier ice gathered some limestone in the lower portion of its course, but the proportion of this rock to the quartzite is so very small that it is difficult to find specimens of it in the drift. The Uinta Canyon glacier of the earlier epoch descended to an elevation of 6,800 feet. In the later epoch the ice descended to an elevation of 7,600 feet.

Mount Emmons, the third highest peak in the range (altitude, 13,428 feet), is west of the Uinta Canyon and east of the East Fork of Lake Fork. It rises in the midst of some of the largest catchment basins in the range, and the view from its summit is instructive and very impressive. The basins immediately surrounding it are numbered 83, 84, and 88, but on a clear day most of the basins from 75 to 93, inclusive, may be seen.

The topographic features in view from the summit of Mount Emmons may be broadly classified in two general groups. In one group are the bare-rock divides, many of them narrow and rugged, rising precipitously a few hundred to 3,000 feet above their surroundings. In the other group are the basin floors, of much gentler topography, clothed, for the most part, with the dense Uinta forest, and bounded by the bold walls that are classed in the first group. The two groups are separated by the sharpest physiographic line that can be drawn in the entire range. The grouping suggested by the general physiographic differences is emphasized when the facts of ancient glaciation are at hand. The first group includes all and only those features that rose above the ice fields. They are the unglaciated, driftless portions of the range. The second group includes all the glaciated areas. The sharp divides have the dark red and purple colors of the pre-Cambrian quartzite; the basin regions are predominantly green, although the deep green of the forest is varied by the light greens and yellows of the meadows. The divides are varied by lofty peaks on which small patches of snow are lodged near the summits and in protected niches, while among the forests in the basins there are scores of beautiful lakes. With field glasses many of the glacial features may be clearly seen and better appreciated than from lower points on the divides or in the basins. The rock benches, with but a scattering of drift, the hanging valleys, the moraine ridges bordering the canyons and those continuing outward from the rock spurs subdividing the basins, come out even more clearly than when seen nearer. Most impressive are the great extent of the ancient ice, and the narrowness of the land areas that rose above it. When the mind replaces the snow which must have rested on the ice and have risen high above the present upper limit of glacial markings, the picture of this portion of the range during the glacial epoch becomes that of a vast field of snow and ice, with occasional dark-red ridges rising above it and roughly subdividing the great mass of ice.

BASIN 87.

Between the Uinta and East Fork of Lake canyons there is a small canyon which heads in basin 87. This basin is an open, amphitheatral area, and the canyon, which extends southward, is symmetrically U-shaped in form. At the margin of the range, where the canyon ends, there is a massive terminal moraine bordered by an outwash plain. The surface of the outwash declines rapidly from the margin of the outermost morainic deposits and loses all distinctive characteristics 2 miles south of the terminal moraine. The outwash plain has been somewhat dissected by wet-weather streams and is crossed to-day by a number of channels. The terminal moraine has a distinctly hummocky topography, with numerous knobs and kettles. In many of the undrained depressions there are lakes, and in a larger number swamps exist. The surface of the morainic deposits is strewn with bowlders, some of which are as much as 8 feet in diameter, and many of these appear to have been recently glaciated. The terminal moraine belt is nearly a mile in width and blends on either side of the gorge into a lateral moraine. From the crest of the terminal moraine the two lateral moraines may be clearly seen. They descend the mountain slope above the valley from an elevation of about 10,500 feet and form belts a quarter of a mile wide on either side of the valley. They are higher than the country east and west of them, indicating that the ice filled the valley in its lower course and deposited its moraines on the divides. The floor of the canyon is masked by ground moraine, which is overgrown by a dense forest.

The catchment area is 10 miles south of the main crest line of the range and 3 miles south of Mount Emmons. The floor of the basin is over 10,500 feet above sea level, and its protecting walls rise 500 to 1,500 feet higher. The area measures about 3 square miles. The basin opens up into a cirquelike space with broad areas, from which most of the loose material has been removed. Heavy drift deposits are lodged in the lower portion of the basin, and among these are a number of small lakes. The thickness of ice in the basin was presumably somewhat more than 500 feet, and the length of the glacier was a little over 8 miles as measured from the rim of the basin to the terminal moraine blocking the mouth of the canyon.

No second moraine could be seen from within or upstream from the terminal moraine described, nor could any trace of an outer, older moraine be found to the south. The deposits seem, however, from their freshness, to belong undoubtedly to the last glacial epoch.

EAST FORK OF LAKE FORK (BASINS 88 TO 93).

The canyon of East Fork of Lake Fork heads near the western margin of the Gilbert Peak quadrangle, and extends southward for about 17 miles to the margin of the range. After leaving the canyon East Fork flows a little west of south, through a broad, open valley, and unites with West Fork of Lake Fork nearly 3 miles south of the southern boundary of Gilbert Peak quadrangle. The catchment area is among the most capacious in the range. The canyon is a beautifully symmetrical U-shaped trough, and the East Fork of Lake Fork glacier during the earlier epoch was among the longest in the range.

Near the junction of the two forks of Lake Fork there are remnants of the outermost moraines of the earlier glaciers which occupied the valleys. These moraine remnants lie on the uplands between the two valleys and also border them on the east and west. The moraine on the interstream area was formed when the ice from the two valleys coalesced, and is a medial moraine. This deposit yet retains a morainic topography, with rolling hills and shallow, undrained depressions. The hills have been softened by erosion and much of their finer material has been washed away, leaving their surfaces bowldery. What the hills have lost the depressions have gained, and at the present time they contain several feet of this fine wash.

The outermost moraines on the uplands, bordering East and West Forks, are of the ridgelike type more common to lateral moraines of valley glaciers. These ridges also show distinct signs of age in the erosion and weathering of their surfaces. In their broader parts, where hillocks and hollows developed, their forms have been largely obliterated by reduction or filling. Some

erosion lines are visible, but in a region so dry it is not surprising that these are not conspicuous, especially in loose material.

A series of beautifully developed terraces lies between these outer moraines and extends far down the valley. Upstream these terraces, three in number, end at distinct morainic ridges which partly cross the valley. The highest terrace ends first or farthest downstream, the middle terrace next, and the lowest terrace last, or farthest upstream. The high-level terrace begins at the outer morainic ridge in the valley and descends, at first with a very steep slope, but later with a more and more gentle gradient. This terrace fits against the sides of the higher lateral moraines, extending down the valley. The second or middle terrace, 40 to 50 feet lower than the upper at the moraines, lies within the remnants of the higher and extends a fraction of a mile farther north to a second set of morainic ridges. Evidently, with the new position of the ice, the stream was able to construct a new flood plain at a somewhat lower level. The lower terraces, which extend still farther upstream, to other morainic ridges, show still later stages of stream cutting. Downstream the upper and middle terraces approach each other and appear from a distance to coalesce several miles below the junction of East and West forks of Lake Fork.

The morainic ridges which partly cross the valley at the upper ends of these terraces rise 15 to 20 feet above the stratified drift at their upstream margins and from 5 to 10 feet above the alluvium at their downstream margins. As approached from the north or upstream side these ridges appear somewhat conspicuous, but when viewed from the south or downstream side they are very inconspicuous. The morainic material in these ridges is almost entirely of quartzite. The larger stones and bowlders are all quartzite and the fine material is sandy. Fragments of limestone obtained by the ice as it passed the zone of upturned Carboniferous rocks are rare. Most of these were probably ground into very fine material, which has been largely removed by solution in postglacial time. The large quartzite bowlders in these moraines are 6 feet in diameter and yet carry marks which, although faint, are interpreted as indicating glaciation. Some stones appear beveled and a number of surfaces bore what appeared to be weathered grooves and striæ. Many of the bowlders are enameled or glazed, and it is on the glazed surfaces that the weathered marks so strongly resembling striæ are preserved. When the glazed surfaces have been weathered off, no marks which suggest glacial work are found. These marks were not, however, satisfactory proof of the glacial origin of these ridges, but the topographic form and position of the deposits, together with their blended connection with unquestioned lateral moraines farther upstream, removes all doubt as to their origin.

Upstream from the morainic ridges, where the terraces begin, the valley is broad and open. The side slopes are deeply eroded. The valley floor is mantled by alluvial deposits washed from the side slopes. The alluvial deposits have broad fanlike forms and at places they so coalesce as to develop an alluvial plain sloping from the valley sides toward the present stream channel. Five miles farther upstream other morainic deposits partly cross the valley. These are lodged among and upon the outcropping strata of the upturned Carboniferous limestone and are continuous with certain lower lateral moraines which descend the valley slopes at this point. The limestone outcrops show evidence of glaciation by their rounded forms, from which all waste has been swept, but postglacial weathering has obliterated any polish or striæ that they may have borne.

The lateral moraines which continue up the valley from the morainic ridges at the limestone outcrops are notably less eroded than those extending farther downstream. East of the east-slope moraine two side streams are ponded by the glacial deposits. In one of these there is a lake, while in the other there is an undrained depression without standing water. On account of the marked difference in the erosion lines, the lower lateral moraines on the valley slopes are in sharp contrast with the upper lateral moraines. In the upper pair, which are the upstream equivalents of the older moraines farther down the valley, the postglacial cuttings are broader, deeper, and more numerous than those in the lower pair. The younger, fresher, and less eroded condition of the lower lateral moraines corresponds to the young erosion features

of this part of the valley, while the more advanced stages in the dissection of the upper lateral moraines correspond with the erosion features of the valley downstream from the frontal moraines at the Carboniferous outcrops. A comparison of the depositional forms in the valley above and below these frontal moraines also emphasizes the contrast between these two portions of the valley and points to the same conclusion, namely, that the portion of the valley below the moraines at the limestone outcrops has been exposed to the agents of degradation and aggradation for a much longer time than has the upstream portion of the valley. From these frontal moraines an outwash or valley train extends 2 to 3 miles downstream, which fits in around the alluvial fans at some places and at others is apparently covered by alluvial wash from the canyon slopes.

The observations on this canyon thus far recorded seem to indicate that the outermost moraines of the valley, the frontal moraines from which the terraces originated, all the lateral moraines upvalley to the Carboniferous limestone outcrops, and even the higher laterals above that point, belong to the earlier epoch of glaciation, and that the moraines crossing the valley at the limestone outcrops, the lower lateral moraines upstream, and the morainic deposits in this portion of the valley floor belong to the later epoch of glaciation.

About 1½ miles north of the moraines at the limestone outcrops a large tributary joins the main stream from the east. The course of this tributary is nearly 9 miles long and was occupied by a tributary glacier. The smaller canyon is U-shaped, with heavy moraines on the side slopes and a general mantle of drift over the bottom. The tributary stream now enters the main valley through a narrow V-shaped notch cut in the massive lateral moraines flanking the main valley. The moraines of the tributary glacier are lodged on the slopes of the smaller valley. The relations at the junction suggest that the tributary glacier retreated from the East Fork glacier while the latter yet extended beyond the junction. This condition could be due to a reduction in the snowfall in the basins or an increase in general surface melting of the glaciers, either of which would produce noticeable effects on the smaller glacier first.

The basin or catchment area is amphitheatral in form and is bounded by precipitous walls from 1,000 to 1,500 feet high. Rock spurs project into the basin and subdivide it into a number of minor basins or cirques. The floor of the upper portion is almost free of loose material, so that broad areas of bare rock are exposed. At the northernmost margin of the basin there is a glaciated shelf which stands fully 300 feet above the general level of the floor. This shelf appears to have been produced by ice plucking at the margin and illustrates an interesting stage in the development of the broad, flat-bottomed catchment areas so common in the range. At least 11 lakes are situated in this tributary basin.

The main valley near the mouth of the tributary and for 2 miles upstream contains no heavy drift deposits on the floor, but the side slopes are masked by lateral moraines for 1,500 feet above the stream. Farther upstream morainic deposits are more abundant in the bottom of the valley, assuming a hummocky topography on either side of the inner rock gorge. This hummocky topography continues in the valley upstream to the lower margin of the catchment basin. In this portion of the canyon the high lateral moraines rest on rock ledges or shoulders 500 to 1,000 feet above the stream. (See fig. 5.) At places the moraines mask the canyon walls so completely that bed rock can not be seen, but the rock appears at intervals short enough to make it certain that the high rock ledges are continuous for several miles. Below and within these rock ledges the valley has a general U-shaped form, modified in the bottom by a sharp postglacial gorge, 50 to 80 feet deep, cut in the solid rock. (See Pl. IX, *A*.) The elevation of these moraines indicates that the glacier at one stage, in this portion of its course, was somewhat over 1,700 feet thick and at least 2 miles wide. Above the lateral moraines in this canyon there are a number of small cirquelike areas,

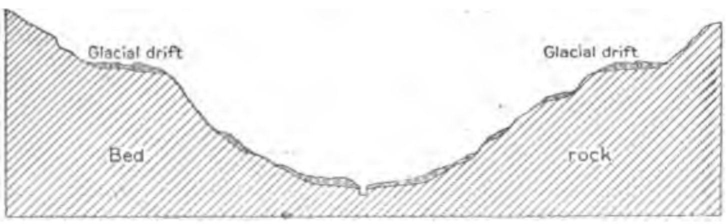


FIG. 5.—Diagrammatic cross section of East Fork of Lake Fork canyon, showing high rock ledges, an inner rock gorge, and the distribution of morainic material.

A. INNER ROCK GORGE IN EAST FORK OF LAKE FORK CANYON.

B. UPPER PART OF PROVO BASIN.

Showing a rock-basin lake and portions of the waste-swept floor of the catchment area. All the passes shown in this view were occupied by ice.

C. LOWER PART OF DU CHESNE CANYON.

Showing alluvial fans extending toward the stream from the side slopes.

which are almost too small to be called hanging valleys, although several of them appear to have been modified by ice action and to have contributed ice to the main glacier. These small, tributary cirques are well cleaned out and are bounded by precipitous walls.

About 6½ miles up the valley from the mouth of the tributary from basin 88 a large tributary from the west joins the main stream of East Fork. This stream now enters the main valley by an obscure course through massive morainic deposits. The canyon it occupies has a favorably located and well-protected catchment area (No. 91), fully as large as that of the main canyon, and the glacier that originated there was probably as massive as the glacier of the main canyon. The lateral moraines of the tributary are lodged on the side slopes about 1,000 feet above the stream, and the valley bottom is heavily mantled with drift deposits. The border of the dense forest in this as well as in the main canyon lies at the limit of heavy drift deposits. In the waste-swept portion many areas of bare rock are exposed.

The greater portion of the tributary canyon may be regarded as a part of the catchment area of the glacier. The stream flows in a depression at the east margin of the area, but to the north and west lie broad stretches of relatively level country bounded by precipitous walls. Twelve lakes have been mapped in this area, but there are at least as many more smaller bodies of water. Around the margin of the basin, as around the margins of many other basins in the range, there is a series of broad rock steps or benches, not the work of running water, but clearly representing stages in the work of the ice in broadening and deepening the great collecting area. At the northeastern portion of the tributary basin the ice was joined with the ice in the basin of the main canyon, and the low col between these basins has been partially cleaned off. South of this col during the glacial period there was a great nunatak, 2½ miles long by one-half mile wide. This unglaciated divide rose from 300 to 800 feet above the ice, which moved southward on either side of it and coalesced at its southern end. A medial moraine over 2 miles in length extends southward from this divide.

The basin (No. 90) of the main canyon of the East Fork of Lake Fork is a capacious amphitheater with some of the loftiest peaks of the range about its margin. King peaks (altitudes 13,496 and 13,498 feet), on the eastern rim, are the highest of the Uintas. Other peaks on the rim rise to elevations of over 13,000 feet. Bare rock surfaces, which are distinctly grooved and striated, are exposed at many places on the floor of the basin. The grooves and striæ all run, in a general way, at right angles to the rim of the basin in the outer portion of the catchment area, and coincide with the general trend of the canyon as the main gorge is approached. Basin 90 is 4 to 5 miles from east to west and 3 to 3½ miles from north to south.

Portions of the basin floor are masked with a thin covering of angular quartzite drift, which at places assumes a rolling or gently hummocky topography. The ice in the basin rested as high as 12,100 feet, nearly the elevation of the pass into basin 45, of Smith Fork. The snows in the basin, which have left no mark to indicate their thickness, must, however, have covered many of the passes, leaving only the high peaks bare. Where the margin of the basin contains drift deposits the tree line corresponds very closely with the upper limit of glaciation, and helps to emphasize the boundary of the area where the ice rested. Small rock basins gouged out at the margin of the catchment area indicate that a considerable thickness of ice rested on the basin floor. The upper surface of the ice was somewhat above the 12,100-foot line. A low medial moraine made up of angular quartzite blocks lies between the two portions of the basin and extends 1½ miles southward. The surface on which this moraine rests is striated at several places, and the striæ have been plotted on the accompanying map (Pl. IV).

The lateral moraines of the canyon, which have been described, begin at the lower or downstream margin of the basin. The highest lateral moraine on the west side begins about 3½ miles south of the main divide of the range, near the southern end of a prominent rock spur. The crest of this moraine at this terminus stands at an altitude of about 11,400 feet, and is separated by a slight hollow from the hill to the west. It stretches southward from the foot of a cliff near the timber line. So far as could be determined at a distance, the left lateral moraine begins at a similar promontory across the valley. When traced southward these lateral moraines are found to rest on rock ledges, as already described.

The inner rock gorge in the bottom of the canyon ends upstream near the lower margin of the basin, about 4 miles from the crest of the range.

The ice in the basin of East Fork of Lake Fork was about 500 feet thick. The maximum thickness of the glacier was at least 1,700 feet and the maximum length was 24.5 miles. The glacier of the later epoch descended 16.5 miles from the crest of the range. The lower limits of glaciation during the earlier and later epochs were 6,600 and 7,900 feet, respectively.

WEST FORK OF LAKE FORK (BASINS 94 TO 104).

West Fork of Lake Fork rises in the eastern part of the Hayden Peak quadrangle. It flows southward and then southeastward, crossing the southwest corner of the Gilbert Peak quadrangle, and thence southward for many miles through the open country south of the range. The catchment area is broad, open, and flat bottomed, with many marginal cirques, characteristic of the south slope. For 7 or 8 miles below the catchment area the stream occupies a narrow inner gorge, but if this inner gorge be neglected, the canyon is U-shaped. Downstream from the end of the inner gorge the canyon widens and the walls become lower and lower until, in the open country beyond the mountains, the glacial moraines actually add to the height of the valley slopes.

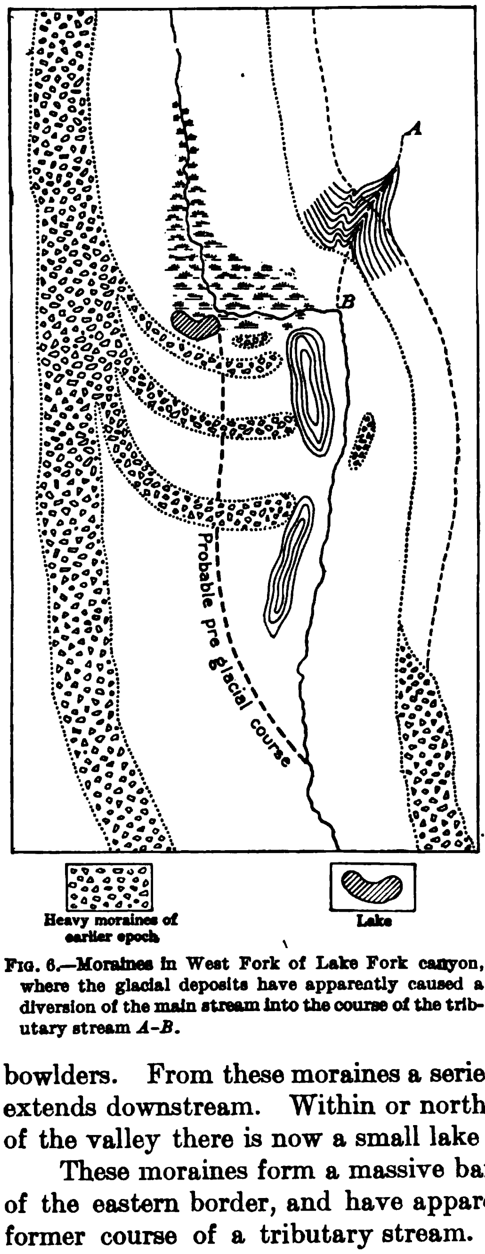


FIG. 6.—Moraines in West Fork of Lake Fork canyon, where the glacial deposits have apparently caused a diversion of the main stream into the course of the tributary stream A-B.

In a general way the morainic phenomena of the lower portion of West Fork of Lake Fork correspond with those of East Fork. A line of massive lateral moraines on the west side, with distinct morainic topography, extends southward for several miles from the mouth of the canyon. Where the moraine leaves the upturned Paleozoic and Mesozoic beds of the foothills its crest has an elevation of nearly 10,000 feet, or about 1,500 feet above the valley bottom. Emerging upon the lower country, underlain by Tertiary beds and here reduced to a beautiful gradation plain, the moraine swings somewhat westward on the interstream surface, forming a strongly pronounced ridge, and within a few miles descends into the valley. Quartzite bowlders 6 to 8 feet in diameter are strewn over the surface of this moraine. The eastern lateral is not so conspicuously developed and is discontinuous. Within the mountain canyon it forms a broad grass-covered bench high above the stream. South of the mountains it coalesces with the west lateral of East Fork and forms an interlobate or medial moraine.

A second series of well-marked moraines descends the west side of the valley about 5 miles upstream from the outermost moraine, just where the steeply dipping beds of Cretaceous limestone and sandstone form conspicuous outcrops in a narrow rock gorge. This group of moraines consists of three distinct ridges, whose surfaces are covered with large bowlders. From these moraines a series of well-developed terraces similar to those in East Fork extends downstream. Within or north of these moraines terraces are absent, and in the bottom of the valley there is now a small lake with an associated marsh, held in by the moraines.

These moraines form a massive barrier across the valley to a point within a short distance of the eastern border, and have apparently caused the diversion of the main stream into the former course of a tributary stream. (See fig. 6.) A short distance beyond the marsh the

main stream makes a sharp turn southward and enters a rock gorge which was presumably the former course of the tributary from the east. It seems that the diversion occurred when the ice front rested where the moraines cross the main valley. At that time waters issuing from the glacier either crossed a low point in the divide between the main valley and the tributary or, following the left side of the glacier, came to occupy the tributary course. When the ice front retreated farther upstream the waters issuing from it were ponded until they overflowed eastward into the course of the tributary.

The material in the outermost moraines and that in those at the upstream limit of the valley train show no striking difference in amount of erosion or weathering. Over 90 per cent of the material is quartzite so hard that the criteria of surface decay can not be applied. Many of the large bowlders, however, have been completely broken to pieces, and a very large percentage have been roughened by weathering. Many smoothed and polished surfaces, presumably glacial, have been worn off in thin flakes. These are the most striking indications of age. The erosion of the moraines has not proceeded far enough to destroy kettle-like depressions.

For nearly 6 miles upstream from the moraines where the terraces begin, the canyon of West Fork is broad and open, with immense alluvial fans washed in from the west wall. One of these fans, just south of the large lake in this fork, advances across the valley and appears to have caused the lake by ponding the stream. No other dam is visible. Aside from the extensive deposition which calls for a long postglacial period there are the corresponding gullies or ravines from which the loose material has been taken. These features help to correlate the drift of this portion of the canyon with that of the earlier glacial epoch in other canyons.

North of the large lake in the course of the main stream the canyon is more constricted and the drift forms are fresher and less modified by erosion. Near the upper end of the lake there are morainic deposits which may well represent the terminal moraine of the later ice advance in the main canyon. West of the lake there are massive moraines, which are interpreted to mark the outer limit of the later ice from basin 104.

The main canyon glacier did not leave very heavy deposits except on the slopes where lateral moraines appear. At places these moraines are 2,000 feet above the stream. Where the tributary glaciers joined the main canyon glacier, the moraines are more massive and at some places medial moraines were developed. The largest medial moraine advances downstream as a distinct morainic ridge for 4½ miles from the rock spur separating basins 98 and 99. The tributary basins from the east, Nos. 94, 95, 96, and 97, each furnished a glacier which was more than a mile in length. These basins, with the exception of No. 94, where the work was not so vigorous, are bounded by precipitous, talus-clad walls. The upper limit of ice work is recorded at the base of the steep slopes, and the activity of the ice is clearly shown by the cleaned-out condition of the basins and the morainic deposits near their mouths. The tributaries are now hanging valleys from which streams descend 500 to 1,500 feet to the main canyon by cascades through narrow postglacial notches.

Basins 98, 99, and 100 may be considered parts of the main catchment area of the glaciers of West Fork of Lake Fork. These basins are located just south of the crest line of the range and constitute one of the most capacious collecting grounds in the whole region. The area included in these great basins is not less than 18 square miles, and the ice which formed there was surely 500 feet thick and probably much thicker. These basins now present a cleaned-out appearance, and contain broad areas of bare rock surface, beautifully polished and striated. Five of the fourteen lakes are in rock basins gouged out by ice action. The upper limit of obvious ice work is at the foot of the steep bounding walls, at an elevation of 11,500 feet. The distinct break from the cleaned-off floor of the basins to the bold but talus-clad walls is one of the best-marked features of the basins.

From the west basins, Nos. 101 to 104, inclusive, large quantities of ice moved to the main glacier. These tributary glaciers formed in basins that ranged from 4 to 8 miles in extent and were bounded by protecting cliffs which rose from 500 to 1,000 feet above the ice fields. Each of these west tributaries is a hanging valley. The stream from basin 101 descends 500 feet in its last half mile; those from basins 102 and 103, 1,000 feet in the same distance; while the stream

from basin 104, by cutting a gorge of 500 feet in rock since the ice left, has removed all but a few cascades from its course. Basin 101 has heavy lateral moraines lodged on either slope and a mantle of drift over most of its surface. Near the head of the basin there are three small lakes. Basin 102 has a low gradient in its upper part, where there are heavy morainic deposits. Among these deposits there are at least seven small lakes. Lateral and medial moraine ridges are present, but largely obscured by dense forest growth. Basins 103 and 104 were continuous in the ice period, but they furnished two distinct tongues of ice to the main glacier. The region included in these basins is now heavily overgrown with timber. The mantle of drift masking the surface has given rise to a rolling and at places a hummocky topography. In the depressions, among the drift deposits, there are no less than fourteen lakes. Brown Duck Lake, the largest of these lakes, is a mile long and nearly half a mile wide. In the tributary canyon below basin 104 the morainic deposits are extremely heavy, developing a belt of very rough, hummocky topography at the lower margin of the basin and massive lateral moraines down to the main canyon of West Fork. The position of the moraines on the slope of the tributary indicates that at least 1,000 feet of ice moved down this gorge to the main canyon. The upper limit of glaciation about these basins is 11,000 feet, which means, as is clearly evident in the field, that the ice in basins 102 and 104 was continuous with that in basins 106 and 107 of the Rock Creek system.

The larger stones of the drift throughout this system of glaciers are derived from the pre-Cambrian quartzite of the great central plateau region of the range. This formation contributed all the material carried by the later glacier. The earlier glacier reached the upturned sandstones and limestones which flank the south side of the range much as the same formations flank the north side. This belt of upturned beds crosses the canyon of West Fork near the large lake at the eastern margin of the Hayden Peak quadrangle, and from there southward the drift contains a larger variety of material, although by far the greater portion is quartzite. The West Fork of Lake Fork glacier was one of the longest in the range, reaching a maximum length of 25½ miles in the earlier epoch and descending to an elevation of 6,600 feet. During the later epoch the West Fork glacier was 14½ miles long and descended to an elevation of 8,100 feet.

ROCK CREEK (BASINS 105 TO 112).

Next west of West Fork of Lake Fork, in the center of the south half of the Hayden Peak quadrangle, is the canyon of Rock Creek, with its system of tributary canyons. The main canyon, heading in a broad, open cirque bounded on the north by the crest line of the range, extends almost directly south for 14 miles and then turns abruptly to the southeast. About 8 miles downstream from the sharp turn to the southeast the canyon reaches the margin of the range and gives way to the broad, open valley in the lower country. A short distance above the abrupt turn, where the stream flows eastward, a sharp inner gorge, such as is characteristic of the canyons of the south slope, appears and continues upstream to the lower margin of the catchment basin.

The canyon of Rock Creek shows signs of glaciation, both in its general form and in its drift deposits, for a distance of 25.5 miles from the crest of the range. The outermost moraines are about 4 miles south of the southern limit of the Hayden Peak quadrangle. At this point massive lateral moraines tend to close in across the canyon. They do not entirely cross the canyon, for the central portion of the terminal moraine has been removed by erosion. Between these outer, lateral moraine ridges, and extending several miles up and down stream, there are remnants of a valley train. These remnants consist of alluvial terraces, now partly masked by alluvial fans washed from the side slopes. The valley train terraces terminate about 2 miles upstream from the outermost moraine, at a pronounced morainic ridge which swings into the valley from the east margin. The ice in Rock Creek canyon, like that of several of the larger glaciers, appears to have retreated somewhat from its lowest position downstream before developing the great valley train.

Near the lowest position of the ice at least three ridges advance toward the stream from each side, suggesting strongly the position of once continuous recessional moraines across the

canyon. The recessional ridge 2 miles above the outer terminal moraine is nearly half a mile wide and has in part a hummocky topography. The lateral moraines in this portion of the canyon consist of three pairs of ridges, the highest resting 1,500 feet and the lowest 500 feet above the stream. The morainic ridges on the west slope are continuous across the mouths of small tributary valleys, and some of them have effectually dammed these side streams, causing them either to seep through the drift or to be ponded. Some of the side streams have cut narrow gorges across the moraines to the main canyon.

In Rock Creek, as in West Fork of Lake Fork, the alluvial side wash tends to choke the valley and force the stream to wind from one side to the other. Local ponding has probably occurred at several points. At the southern margin of the Hayden Peak quadrangle the stream, now partially blocked by a fan, meanders in an intricate fashion—much more intricately than could be shown on the map. Taking all the observed facts into consideration, the lower 5½ miles of the glaciated portion of Rock Creek canyon appears clearly to belong to the area invaded by the more extensive ice of the earlier epoch, but not reached by the later ice.

About 5½ miles upstream from the outer terminal moraine, fresher looking moraines, less modified by postglacial erosion, close in nearly across the canyon. These terminal moraine ridges blend into lateral moraines which become higher and higher on the canyon walls until, at the abrupt bend in the gorge 6 miles above the younger terminal moraine, the lateral moraines rest at an elevation of 2,000 feet above the stream. In these 6 miles of the canyon the lateral moraines are especially heavy. North of the abrupt turn in the canyon of Rock Creek, in the more rugged portion, where the inner rock gorge exists, the lateral moraines noted farther downstream persist. These moraines are exceedingly heavy lodgments of drift mantling the canyon slopes from the rim of the box canyon to an elevation of 2,000 feet above the stream. At the junction of the tributary glacier from basin 112 with the glacier of the main canyon, the ice rested 2,500 feet above the present stream bed. At this elevation a great rock ledge shows signs of abrasion by the ice and a medial moraine begins. This medial moraine is but a thin, though ridgelike, covering of drift resting on solid rock, but it maintains its characteristic form for nearly 2 miles down the canyon. Other tributary glaciers assisted in the formation of medial moraines. The most conspicuous of these medial moraines is located between the main canyon and basin 107. This moraine extends as an unbroken ridge for 3 miles down the main gorge.

The tributary basins on the east, Nos. 105, 106, and 107, furnished a large amount of ice to the Rock Creek glacier. The ice from basin 105 was not vigorous; it seems to have done very little eroding, but rehandled the available loose material and left it in morainic forms strewn over its course and at the junction with the main canyon. This tributary is now a hanging valley. Basins 106 and 107 were continuous during the glacial period and they are not very distinct now. The ice which formed in these catchment areas moved over relatively low gradients to the border of the main canyon, where the stream now cascades down 1,000 feet in the last mile. The tributary ice was not very vigorous, but redistributed the looser material that mantles the floor of the basins. Among these drift deposits in basin 106 there are three small lakes, while in basin 107 there are nine such lakes.

The main catchment area of Rock Creek canyon, including basins 108 and 109, is a broad, flat-bottomed, amphitheatral area, 24 square miles in extent, bounded by precipitous walls. From one of the lofty peaks in the crest line of the range 20 glacial lakes were counted in this great collecting ground. Four of these lakes are known to be in rock basins. The catchment basin has been so well cleaned out that there are now continuous areas, square miles in extent, where there is not sufficient loose material for trees or shrubs to gain a footing. Three inconspicuous morainic ridges in the western portion are the chief drift forms to be noted. The thickness of the ice in the main catchment area was not less than 800 feet and was probably much greater.

Southwest of the main catchment area, in the region covered by basins 110 and 111, there was an immense ice field, which was tributary to the Rock Creek glacier. This ice field was continuous with the great ice cap that centered about Bald Mountain, in the western portion

of the range. These basins are not sharply defined and yet about 25 square miles of ice, 500 to 1,000 feet thick, formed in them. The floor of this area is covered by heavy morainic deposits overgrown by a dense forest. With the exception of a few ridges of drift these deposits have been classed as ground moraine. The area is rolling, with immense undrained depressions, and is remarkable both for the number and the size of the lakes it contains. Forty-three lakes have been mapped, but it would be an almost hopeless task to find all the lakes, for they are so nestled among the trees that many of them would not be discovered unless they were actually reached in traveling through the forest. The largest of these lakes is known as Lake Grandaddy. The chain of three lakes in the course of the main stream of the basin is held in by a series of slight morainic dams. Four small lakes on the pass between basins 111 and 113 are in rock basins bordered by polished and striated rock surfaces. Two of these lakes do not appear on the topographic map.

Basin 112 also furnished a tributary glacier to the main Rock Creek glacier. This tributary ice formed between high protecting walls and moved 5 miles as an independent glacier. In that distance the ice cleaned off most of the loose material from the floor of the basin, gouged out three rock basins which now contain lakes, carried vast quantities of superglacial material contributed by the steep canyon walls, and built up immense moraines at the mouth. These moraines are strongly suggestive of a terminal moraine developed by this tributary glacier during the later epoch, when this ice may have reached only to the margin of the ice of the main canyon.

The glacial drift in Rock Creek canyon and its tributaries is of the same character as that in the West Fork of Lake Fork. The ice formed in the same quartzite formations and moved past the same series of upturned sandstones and limestones on the flanks of the range. The drift of the later epoch is composed entirely of material derived from the Weber quartzite. The outermost moraines belonging to the earlier epoch contain an inconspicuous proportion of sandstones and limestones. The outermost moraines are 25.5 miles from the crest of the range and stand at an elevation of 6,700 feet. The younger terminal moraine is 20 miles from the crest line and stands at an elevation of 7,600 feet.

DU CHESNE CANYON (BASINS 113 TO 117).

Du Chesne Canyon is in the southwest quarter of the Hayden Peak quadrangle. The catchment area is just south of the crest line of the range and is included in the territory covered by the ice cap which centered about Bald Mountain. About the rim of the basin are several of the more conspicuous peaks of the western portion of the range. The canyon is a broad U-shaped trough, which turns somewhat to the west in the middle part of its course, but maintains a general southward direction to the margin of the range. An inner rock gorge, beginning a few miles below the basin, continues for 7 or 8 miles downstream. The formations seen in the canyon range from the dark red and purple quartzite of the central portion of the range through the gray limestones and light-red sandstones of the flanks to the much younger and horizontal beds of the lowlands.

The outermost moraines in Du Chesne Canyon are over 2 miles south of the Hayden Peak quadrangle, more than a mile south of the junction of West Fork of the Du Chesne with the main canyon. These moraines consist of heavy ridges resting on the east side and curving somewhat into the valley. South of the mouth of West Fork these ridges rise but 30 to 50 feet above the alluvial terrace in the valley. They contain a preponderance of quartzite bowlders, brought from the core of the range, and some limestone and sandstone from the lower portion of the course. No terminal moraine is associated with these outermost ridges, nor are there any corresponding lateral moraines south of West Fork on the west side of the valley, though such moraines presumably once existed and have been washed away. Farther upstream there are a few remnants of lateral moraines which might be connected with these outermost ridges.

The alluvium in the valley is a portion of a great outwash or valley train which extends for miles beyond the outermost moraines and upstream to a pronounced terminal moraine near the

junction of the West Fork with the main canyon. This terminal moraine blocks the valley except in the stream gorge at the west margin. At the downstream margin of the moraine there are a number of crescentic ridges representing successive positions of the ice front. Within, or north of, these drift ridges the surface is irregular, with low hills and some undrained depressions. The terminal moraine belt at this place is fully half a mile wide.

Less than a mile upstream from the inner margin of the terminal moraine just described there is another massive drift deposit, which advances from the east side as a recessional moraine and nearly crosses the valley. Farther up the canyon there are heavy lateral moraine deposits on the east side, but the west wall, for nearly 3 miles, is too steep to carry much loose material. The moraine on the east side has been deeply notched at several places by tributary streams. On the west side there are several hanging valleys, some of which contain morainic deposits at their lower ends. Some of the streams from these hanging valleys have cut narrow V-shaped notches through the drift deposits and into the solid rock. The elevation of the lateral moraines increases gradually until, at a distance of about 6 miles from the outermost moraines, near the mouth of Hades Canyon, they stand 1,700 feet above the valley bottom. In that same distance the moraines become more widely separated, indicating a greater width to the glacier in the central portion of its course. At the outermost moraines the width of the glacier must have been a little more than a mile. At the mouth of Hades Canyon the width on the surface was over 2 miles. The cross section shown in fig. 7 gives the dimensions of the Du Chesne glacier a little north of the junction of the Hades Canyon glacier.

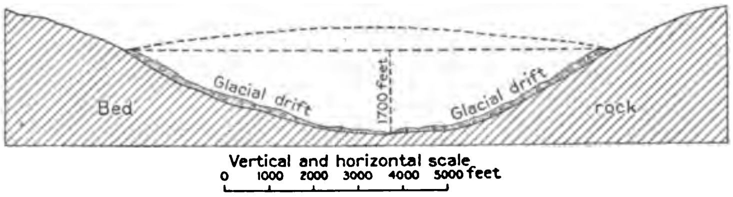


FIG. 7.—Cross section of Du Chesne Canyon, near the mouth of Hades Canyon. The section is drawn to scale and shows the position of the lateral moraines and the dimensions of the glacier at this point.

In the bottom of the canyon, throughout the portion thus far described, there are heavy alluvial fans. (See Pl. IX, *C*.) These fans correspond to the notches cut in the lateral moraines and spread outward into the valley so as to cause the stream to wander from one side to the other. The fan opposite the mouth of Hades Canyon is perhaps the largest, but it may represent wash from the end of the Hades Canyon glacier of the later epoch as well as postglacial wash from that tributary. The amount of alluvium deposited by the side streams corresponds approximately with the amount of erosion in the lateral moraines.

The only tributary that furnished ice to the Du Chesne glacier in its lower portion came from basin 113 and moved down Hades Canyon. The ice in this basin was at least 500 feet thick and moved southwestward as an independent glacier for about 5 miles before joining the main glacier. In the earlier epoch the ice presumably assisted in developing the glacier of the main canyon, but in the later epoch the Hades Canyon glacier terminated at the margin of the main gorge. The younger terminal moraines are massed at the mouth of the tributary, where they rise from 1,000 to 1,500 feet above the stream. Up the canyon the deposits are exceedingly heavy, so heavy that it is almost impossible to get through the gorge with horses. Toward the basin the amount of drift decreases, and in the upper portion of the area bare rock surfaces that show glacial polishing and striation are exposed.

The moraines that mark the maximum extension of the later ice in the main canyon are nearly 9 miles upstream from the outermost earlier moraines. At an elevation of approximately 8,000 feet they swing in across the valley as crescentic ridges. Farther upstream the canyon contains heavy morainic deposits, both on the side slopes and in the bottom. The contrast between this portion of the canyon and that below the younger terminal moraine in the amount of postglacial erosion and deposition is very striking and indicates that the deposits in the lower portion of the canyon are much older. The younger moraines are overgrown by a dense forest, which obscures all the details of the deposits. The forest in the canyon is practically impenetrable for horses. No trails exist there and in the dense woods very little can be seen.

From basins 114 and 115 ice was contributed to the main glacier. Each of these basins has the characteristic U-shaped trough below it, but they are so densely overgrown by forests that all details are obscured.

Basins 116 and 117 may be considered the main catchment area of the Du Chesne glacier. To the northeast of this area a continuous bounding wall rises 500 to 1,500 feet above the floor of the basin, but to the northwest, west, and southeast the rim of the basin is not sharply marked. To the northwest and west a few peaks rose as nunataks above the vast snow fields associated with the ice cap of this portion of the range. Most of the floor of the basin area is above 10,000 feet. The upper limit of ice action is about 11,500 feet. About the margin of the area near the crest line there are scattered patches of drift and broad areas of beautifully glaciated rock surfaces. In these rock surfaces there are shallow basins containing lakes.

The lower portions of the basins are masked by morainic deposits, which are now obscured from general view by dense forests. Among the drift hills there are numerous lakes and meadows. Thirty drift-basin lakes have been mapped in this collecting area, and five rock-basin lakes, the latter being in basin 116. The upper limit of glaciation about the margin of the basin corresponds approximately with the upper limit of trees.

In constitution the drift of Du Chesne Canyon can not be differentiated from that of the many other canyons already described. The sameness of the rock formations throughout the range has given a sameness to the composition of the drift. The main body is quartzite and materials resulting from the disintegration of the quartzite. In the lower course, however, the customary limestones and sandstones, already mentioned in connection with the older drift deposits, appear, and they contributed much fine material to the drift.

The glacier of the earlier epoch in Du Chesne Canyon was 21 miles long and descended to an elevation of approximately 7,400 feet. The glacier of the latter epoch in the same canyon was 12 miles long and descended to an elevation of 7,900 feet.

SOAPSTONE CANYON (BASIN 118).

Near the southwest corner of the Hayden Peak quadrangle, at the head of Soapstone Creek, there is a small catchment area from which a narrow tongue of ice moved westward for a distance of 4 miles and descended to an elevation of 8,600 feet. This basin is on the flanks of the range, in the zone of limestones and sandstones, at an elevation of between 9,000 and 9,500 feet. It shows less distinct signs of ice occupancy than any other glacier basin in the range. It does not have a cirquelike form, and it is not so well protected as any other basin that furnished a glacier. The glacial deposits in the valley have been so modified that their morainic forms can scarcely be recognized. A few remnants of loose débris, however, are so lodged on the valley slopes that it would be difficult to explain them on any other hypothesis than that of glaciation, and a low ridge, partially crossing the valley, marks the position of the terminal moraine. Downstream from the terminal moraine ridge there are alluvial or outwash deposits.

The evidence that a glacier occupied this basin would have seemed weak and possibly inconclusive were it not for a single exposure where distinctly and beautifully striated bowlders were found. This exposure is in a prospector's tunnel on the north side of the valley, about a mile and a quarter upstream from the terminal moraine. The striated material is limestone, which is the chief constituent of the glacial drift in the valley. The exposure is near the base of the valley slope, at a place where there appears to be no morainic deposit. The excavation shows 2 to 3 feet of angular side wash overlying the glacial drift. It is quite possible that at many other points in the valley postglacial wash may have buried glacial moraines.

There is little doubt that the records of ice action in this valley belong to the earlier epoch and that no glacier existed here during the later epoch. There appears to be no reason for dividing the deposits; on the contrary, there is every reason for classing them together as of common age. The basin is small and unfavorably situated for glaciation. The deposits are deeply eroded, and the amount of postglacial weathering and side wash is far greater than in any portion of the range that was occupied by ice during the later epoch. The limestone of this region weathered more rapidly than the quartzite in the other canyons of the range, but

this factor does not offset the deeper and more extensive stream erosion found here. Furthermore, the postglacial work in Soapstone Valley corresponds with that in the lower portions of the larger canyons which were not invaded by the later ice.

PROVO CANYON (BASIN 119).

The canyon of Provo River heads among the lofty peaks at the west margin of the Hayden Peak quadrangle. After following a general southward direction for 7½ miles, the canyon turns abruptly to the west, enters the Coalville quadrangle, and after a sinuous course leaves the Uinta Mountains near their western end. Provo River flows southwestward from the Uinta Mountains, cuts through the Wasatch Mountains, and empties into the Great Salt Lake drainage system near the city of Provo.

In the upper 7½ miles of Provo Canyon the stream crosses the upturned edges of the southward-dipping quartzite layers that constitute the core of the range. Beyond the point where the canyon turns westward the stream runs approximately along the strike of the same quartzite formation to the place where the canyon broadens out into what is known as Pine Valley. Traversing Pine Valley southward the stream crosses the strike of limestone and sandstone layers on the flanks of the range.

On the slopes of Pine Valley there are remnants of moraines and of outwashed alluvium. The lower limit of the moraines is about 7,500 feet. Between these remnants there is a very persistent alluvial terrace, which extends many miles downstream from certain distinct terminal moraine ridges formed by glaciers that entered the canyon from tributary canyons.

A terminal moraine in the main Provo Canyon appears at the upper end of Pine Valley, just above the junction of the North Fork of Provo with the main stream. (See fig. 8.) This moraine consists of a series of low ridges which rise 10 to 30 feet above the alluvial or valley train filling. Farther upstream other morainic ridges advance into the valley as recessionals, and these also are bordered and partially buried by alluvium. For 5 miles upstream from the terminal moraine just referred to there are massive lateral moraines lodged high on the south wall of the canyon. At the mouth of Soapstone Creek, a tributary from the south, the crest of the highest lateral moraine of the main canyon is 1,200 feet above the bed of Provo River, and on the opposite side of the canyon scant morainic remnants rest at the same elevation. Above the mouth of Soapstone Creek the broad, open, U-shaped form of the canyon persists, but the canyon walls are at many places too steep to have permitted the lodgment of much drift.

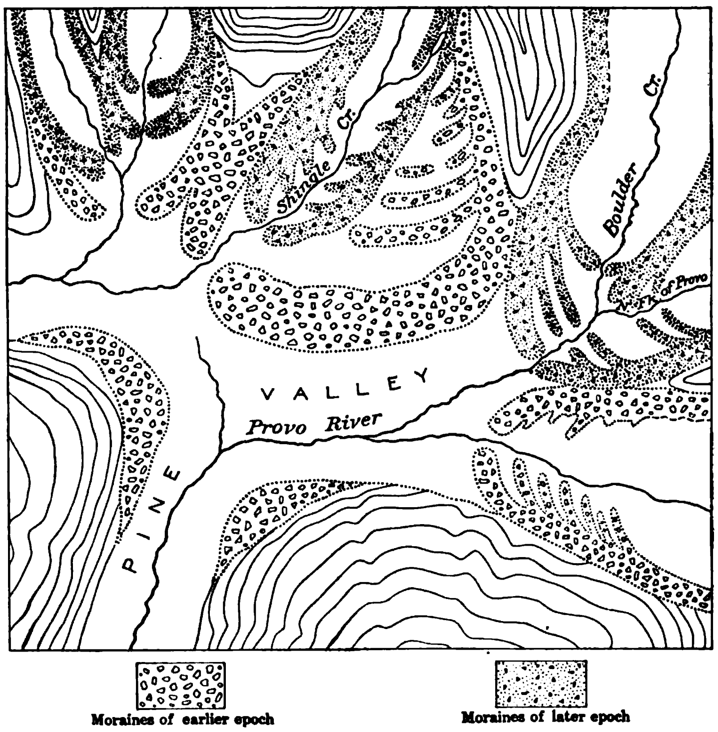


FIG. 8.—Sketch map showing the arrangement of morainic ridges in the vicinity of Pine Valley.

About 7 miles from the head of the basin the canyon becomes very different in appearance. Fresh and massive moraines swing in from the sides and approach the margin of the modern stream gorge. Heavy deposits are lodged in the bottom of the canyon, in the manner of recessional moraines, and the side slopes are masked with drift. The erosion features in the drift indicate a relatively shorter period of exposure than has elapsed since the deposition of the

moraines in the lower portion of the canyon. In short, the upper 7 miles of Provo Canyon would seem to have been glaciated at a much later date than the portion farther downstream. The nature of the drift is of very little assistance in discriminations as to age, for the material is quartzite throughout, and such a hard variety of quartzite that even that which has been exposed to the processes of weathering since the earliest retreat of the ice does not yet show much sign of disintegration. In some places the amount of soil or humus on the older drift is noticeably greater than that on the younger, but more often this difference is not sufficient to be of very great value in discriminating between older and younger drift deposits.

The catchment area of the main Provo glacier is continuous with that of the Du Chesne, the Weber, and the North Fork of Provo, and is a part of the area covered by the great ice cap of this portion of the range. This catchment area contains about 16 square miles, and although the passes were all covered by ice, it yet retains a basin-like form. The lowest places in the rim are several hundred feet above the floor. During ice occupancy only seven peaks about the rim of the basin rose above the snow fields.

The passes are, for the most part, free from loose material, and the bare rock surfaces are beautifully smoothed and polished. At places the ice gouged out basins in the solid rock, where lakes are now found. At the north base of Mount Watson, which is located on the northwest rim of the basin, there are ten such rock-basin lakes. One of these lakes is shown on Pl. IX, *B*. In this pass north of Mount Watson the striæ are well marked, and within a distance of 100 yards indicate ice movement in opposite directions, part moving down a branch of the Weber into basin 14 and part down the Provo. The passes from the Provo Basin to basins 15 and 16 on the north slope are also polished and striated. In the latter of these passes there are five rock-basin lakes.

The floor of the Provo Basin has a hummocky topography, resulting from very heavy and irregular deposits of drift. Among the drift hills there are numerous lakes, hidden in a dense forest. There are also numerous meadows in the basin, marking the sites of former lakes. From Bald Mountain, a high peak on the eastern rim of the basin, 43 lakes were counted in the Provo Basin.

Bald Mountain affords an unusually favorable point for viewing the area covered by the ice cap and for studying many of the features due to glaciation near the crest line of the range. From the summit four large catchment areas may be examined—the Du Chesne, Hayden Fork of Bear, the Weber, and the Provo.

Under a clear or partly clouded sky the view from Bald Mountain is magnificent. In the dense pine forests of the basin region at least 70 lakes may be seen. Some of these lakes have a beautiful blue color, while others appear green; some lie in deep shadow, while others gleam silvery white from reflected sunlight. The waters of most of these lakes are commonly quiet, yet the surfaces of some of the larger ones may be rippled, or at least rippled at the leeward ends, where the winds, descending from the treetops, strike the water. In the forest there are also many meadows, some of which occupy the basins of former lakes while others skirt the margins of the present lakes. The meadows are green, but of much lighter shades than the deep, dark greens of the forest. Above the forest rise some of the most picturesque peaks among the Uintas.

NORTH FORK OF PROVO AND BOWLDER CREEK CANYONS (BASINS 120 AND 121).

The canyons of the North Fork of Provo and of Bowlder Creek are near the eastern margin of the Coalville quadrangle. Their basins, 120 and 121, are just south of the crest line of the range, at an elevation of about 10,000 feet. The canyons extend southwestward for about 9 miles and then open into the upper end of Pine Valley.

In the catchment areas the ice was continuous, and in fact might be considered a portion of the great ice cap that centered a few miles to the east. Below the catchment areas the ice was separated for a distance of about 3 miles by a narrow nunatak ridge, and then coalesced, forming a single glacier which advanced in the later epoch to the margin of the more open valley beyond. In the earlier epoch these canyons presumably contributed ice to the glacier that

moved farther down Pine Valley and left the outermost moraines already described in connection with the main Provo Valley.

The moraines of the later epoch built by the ice from the North Fork of Provo and from Bowlder Creek at the position of maximum extension are represented on the sketch map forming fig. 8. The outermost ridge stands at an elevation of about 7,600 feet. It curves symmetrically from the east wall of North Fork to the west wall of Bowlder Creek, and brings out beautifully the lobate terminus of the glacier. It is a relatively narrow ridge with an even crest line, and descends from the east wall of North Fork at an angle of about 9°. This angle must represent approximately the surface slope of the glacier near its lower end. Near the stream this outer morainic ridge is at least 150 feet thick, but a few miles up the canyon its thickness increases to several hundred feet.

Downstream from the terminal moraine a morainic apron is spread over the alluvial terrace of the earlier glacial epoch. This younger outwash has a higher gradient than the older, and blends with the lower about a mile downstream. The terminal moraine rises about 100 feet above the upper margin of the outwash slope. Upstream, or within the outer terminal moraine ridge, there are several other distinctly morainic ridges. They are all lower and therefore less conspicuous than the outer ridge. In height they range from 30 to 50 feet above the surrounding land. Two of these inner ridges appear to have been developed by the united ice from the two canyons.

Farther up either of the streams there are other recessional ridges, but, as shown in fig. 8, they were made at a stage in the retreat when there were two distinct ice tongues. The corresponding spurs of these ridges are in the same canyon. Between the two canyons, resting high on the dividing ridge, there is a massive medial moraine, which extends for about 2 miles beyond the nunatak ridge that separated the glaciers in their middle portions. In the North Fork of Provo there are no heavy lateral moraines, for the canyon walls are too steep to permit the lodgment of loose material. The walls have been cleaned off by the ice for at least 1,000 feet above the stream. Glacial striæ were found 600 feet above the stream. In the canyon bottom there are high quartzite ledges, beautifully polished, grooved, and striated. On some of these bare rock surfaces potholes were seen, which are probably due to the action of superglacial streams, which fell through crevasses and set up a churning action on the underlying rock.

Toward the basin the drift becomes more and more scarce, until, in the upper portion broad areas of bare rock are exposed. In rock basins and among the scant drift deposits in the basin there are at least eight small lakes. The basin comprises about 6 square miles, and the ice field was probably not less than 700 feet thick.

In the lower portion of Bowlder Creek canyon there are some heavy deposits of drift, especially to the west of the stream. The canyon walls retain but little loose material and there is but an irregular scattering of drift on the bottom. Near the basin there is a series of rock steps or benches, from which most of the loose material has been removed and on which striation and glacial polishing are well shown. In the northwest portion of this basin there are at least four lakes in rock basins. The passes from this collecting area to the basins on the north slope have been glaciated, and in the one leading to basin 8, on the north slope, striations are abundant. They show signs of ice movement in opposite directions within a few rods of the divide. The basin contains approximately 4 square miles, and the ice in it was probably 700 feet thick. The upper limit of ice action was at about 10,600 feet. The drift of the North Fork of Provo and Bowlder Creek canyons is composed entirely of quartzite, for the ice in these canyons did not advance beyond the outcrop of that formation.

SHINGLE CREEK (BASIN 122).

During the earlier epoch the Shingle Creek glacier probably contributed to the ice that deposited the outermost moraines in Provo Valley and on the south slope of Beaver Creek. During that epoch the Shingle Creek ice appears to have retreated from its maximum position and stood at the mouth of the canyon for a long period, contributing to the valley train alluvium in Provo Valley and building up an enormous moraine.

The arrangement of the morainic ridges at the mouth of Shingle Creek is shown in fig. 8. The outermost ridges are interpreted as belonging to the earlier epoch, and the inner system to the later epoch. The inner system appears to represent the work of a narrow tongue of ice which pushed through the older moraines, along the line of the main trough, and left a series of ridges not in accord with the outer series. Each system has a series of recessional ridges, marking the position of the ice margin on retreat, and it seems impossible to correlate the recessional ridges of the two systems so as to account for them by supposing that they were deposited at the retreating margin of a single glacier. The outermost ridge of the older system appears to contain 500 to 800 feet of drift. The lesser ridges of this system rise 50 to 100 feet above their surroundings. The lateral moraines of the inner system rise 300 to 500 feet above the stream, and the recessional moraines of this system appear as spurs about 50 feet high jutting out into the main valley.

Two miles upstream from the junction of Shingle Creek with Beaver Creek there is a precipitous rock cliff in the midst of the canyon. Above the cliff the canyon has a symmetrical U-shaped form, heavily masked with morainic deposits. The cliff was undoubtedly the scene of active plucking by the ice during the glacial period and the site of magnificent falls immediately after the retreat of the ice. Since then the stream has lowered its course 50 to 100 feet and flows through a narrow rock-bound gorge until it gets beyond the cliff.

The Shingle Creek catchment area, No. 122, is for the most part 9,500 feet above sea level, and a portion is about 10,000 feet. Around the margin of the basin there is a narrow zone from which most of the loose material has been removed, but the larger portion is covered by morainic hills which are irregularly distributed and best classified as ground moraine. The ice in the basin was probably not less than 700 feet thick. It was continuous with the ice in basins 7 and 8 on the north slope and that in basin 123, to the west. The upper limit of ice action is at an elevation of about 10,500 feet.

BASIN 123.

Basin 123 can not be distinguished sharply from basin 122. The two are really portions of one large catchment area, but a distinct glacier moved southward from the western portion of this area. Possibly the ice of the earlier epoch from basin 123 moved across the valley of Beaver Creek and assisted in depositing the moraines on the south slope of that valley. The ice of that epoch certainly reached the valley of Beaver Creek, for old moraines are lodged at the junction of the tributary with the main. The arrangement of these moraines is shown in fig. 8.

During the later epoch the ice did not advance as far as in the earlier, and the younger moraines are lodged at the mouth of the gorge. These moraines are ridgelike in form and so massive that when seen from Beaver Creek they appear to block completely the mouth of the gorge. They are little modified by erosion and appear clearly to belong with the youngest glacial deposits in the range.

The collecting area corresponds in elevation with that of the Shingle Creek glacier, from 9,500 to 10,100 feet. The floor is heavily covered with ground moraine, which is overgrown with forest. Among the drift deposits there are numerous small lakes and swamps.

BASIN 124.

Basin 124 is the westernmost area on the south slope of the range that furnished a glacier. The ice formed just south of the main crest line, where the elevation is between 9,500 and 10,000 feet. From this area the movement was southwestward over a very steep gradient for a distance of nearly 5 miles.

During the earlier epoch of glaciation the ice from this basin crossed Beaver Creek valley and lodged moraines on the south slope of that valley. On the north slope of Beaver Creek valley the older moraines outflank the deposits of the later epoch. The older moraines are but remnants of former ridges. They are composed chiefly of quartzite and therefore are easily distinguished from the limestone hills to the south and west.

The younger system of moraines is lodged in the main gorge and extends but 3 miles from the head of the basin. In the lower portion of the course there are well-preserved ridges, but in the basin the drift is irregularly distributed in the form of ground moraine. The ice was probably 500 feet thick in the basin and 800 feet thick in the valley below. Beyond the younger terminal moraine there is an immense alluvial-fan outwash which advances into the valley of Beaver Creek.

NÉVÉ FIELDS.

Within the area studied several névé fields have been located, and they are indicated on the general map accompanying this report (Pl. IV). These accumulations of snow, many of which were probably accompanied by the formation of impure ice, had some movement. The material moved is all angular and at places is arranged in irregular ridges which, here and there, inclose lakes. The basins of such névé fields do not show such scouring or cleaning as characterizes the glacier basins, nor are the erosion lines in them so completely erased. It is impossible to determine just which of the basins not mapped as glaciated contained névé fields without glacier ice, and which contained a small amount of ice in addition to the névé.

LANDSLIDES AND LANDSLIDE TOPOGRAPHY.

The amount and widespread distribution of landslide topography in the region examined has caused no little trouble in the study of the glacial formations. Landslides and large areas of typical landslide topography have been found at several places in the range, but at no place do they occur on such a remarkable scale as in the northwest portion of the Hayden Peak quadrangle. This remarkable development is restricted to the area where the Tertiary conglomerate is the chief formation. The material is therefore nearly and often quite identical with the glacial drift. The ice which reached portions of this region had passed over the same formations that furnished the material for the conglomerate, and that of the longer glaciers actually gathered material from the Tertiary conglomerate, carried it for a longer or shorter distance, and deposited it as glacial drift.

In many places in other portions of the range the local and angular nature of the material has been of great assistance in distinguishing landslides from moraines, but where landslides have developed in the Tertiary conglomerate near the borders of the range, where ice work might be expected, this criterion has not been applicable. The absence of striæ on the landslide material and their presence on the glacial bowlders might be suggested as a ready means of discrimination, but in all the glacial drift of the range few striated bowlders have been found. Where the drift is composed exclusively of quartzite, striæ are usually absent; where the drift is a lateral moraine, which was carried chiefly on the surface of the ice, few striated stones are found in it; where the drift is composed of but slightly rehandled Tertiary conglomerate striæ are very seldom found.

A landslide topography and a topography developed by deposition from ice are, as a rule, distinctly different. In some places, however, the landslide topography is so similar to that developed by ice that, if the location or topographic relations were not known, the topography would be pronounced morainic, resembling most closely that of a terminal moraine. Possibly some of the topography classed as landslide topography may be, in part, due to névé work. In each area the question has been whether true glacier ice or landslides assisted by névé work have developed the topography. The chief criteria used have been, first, the topography of the material; second, the topography of the basin or valley affected; and third, the topographic relations in the basin or valley.

Landslides that lie as knolls on the sides of hills have unmistakable topographic features. The knolls or prominences are as a rule longer than they are wide, and their longer axes lie approximately parallel to the trend of the hill and to each other. The knolls are of about the same size, and the higher ones are much fresher in appearance than those lower on the slopes. Above the uppermost knoll or short ridge, there is, very commonly at least, a sheer

cliff which was laid bare at the last slumping. The material in and just above the cliff is the next to slide down, and when it comes to rest, it will most likely retain, for some time, an abrupt cliff-like outer face. Many of the older knolls and ridges retain steep outer faces. As the sliding mass moves outward, and possibly rises up over the mass which last preceded it, a small basin may be formed, in which water may collect. Many lakes exist among landslides, but most of them are due to the arrangement of three or more landslide masses so placed that they inclose small areas. Such lakes at the base of cliffs or steep slopes among the mountains resemble in position certain glacial lakes. On a topographic map some of these landslide lakes are very suggestive of glaciation, and are therefore misleading.

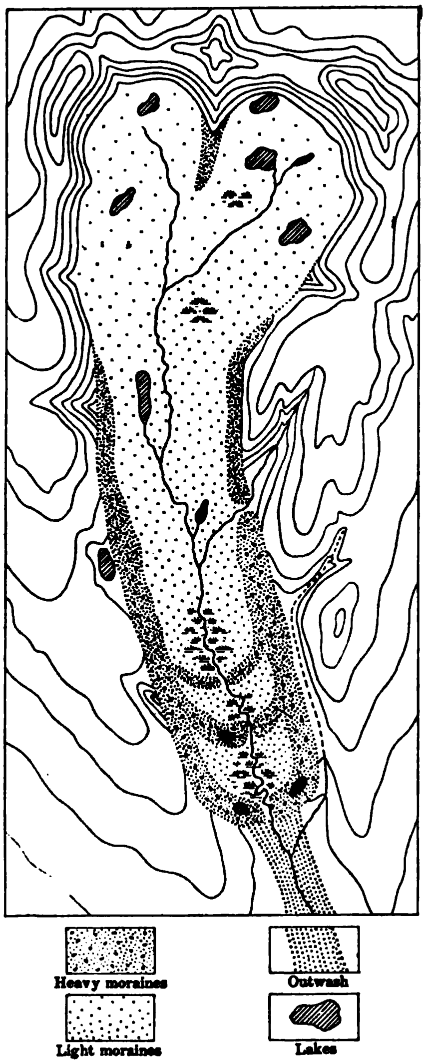


FIG. 9.—Diagrammatic sketch of a glaciated valley, showing the usual form of a basin, the location and arrangement of the moraines, several blocked tributaries, and a typical outwash or valley train.

A lateral moraine may usually be distinguished from a landslide area on the side of a valley by an even-crested ridge at the outer margin of the moraine. The even crest of the ridge will descend gradually down the valley, as the surface of the glacier did. The lateral moraine may lie across the mouths of tributary valleys, and thus rest in places where a landslide ridge could not be located. The continuous ridge of a lateral moraine presents a sharp contrast to the short, independent ridges in landslide areas. The approximate evenness of the elevation of the moraine above the stream differs from the irregularity in elevation shown by landslide ridges which lie at different heights on a valley wall. Within or below the outer ridge of a lateral moraine there may be an area of hummocky topography, exhibiting a very irregular assortment of hills and ridges, irregularly distributed. Morainic hills do not have the steep or cliff-like faces common to landslide hills; they do not commonly have one axis notably longer than the other, and even if elliptical in form, they are as likely to have their longer axes at right angles to the valley wall as parallel to it. When a landslide mass blocks a valley, it does not form a ridge that swings out into the valley as a terminal or recessional moraine. It usually lies on but one side of the valley, and is there so irregularly massed as not to suggest the symmetrical outer ridge common to moraines. Furthermore, landslide masses blocking a valley do not connect with definite forms upstream on the valley walls, as the terminal and recessional moraines connect with lateral moraines.

A landslide area that has been softened by erosion and somewhat removed from any cliff suggesting its source is more difficult of recognition. Such areas have been found fully a mile away from cliffs where landslides are now developing. The landslide masses may not have traveled outward for any great distance, but the cliff from which they originated has retreated as the process of slumping has gone on. In these cases the hills have actually lost their characteristic forms, and the depressions that may have contained water have been modified by deposition and vegetable growth. The criteria to be used here are the topographic relations of the area and the general topography of the basin and associated valley.

Glacial moraines are commonly arranged as shown in fig. 9, suggesting in a general way the form of the ice lobe that developed them. The places in this system to expect hummocky

topography are the terminal or recessional moraines or the bottom of the valley. Where the topography of a basin and associated valley has been modified by landslides, possibly assisted by névé, the arrangement of these deposits is somewhat as shown in fig. 10. In this case the whole area affected may have a hummocky topography, the hummocks or hills may mask the greater portion of the floor of the basin, and may at places extend nearly or quite across the valley. The chief contrasts in the arrangement of the deposits shown in the two figures are:

1. The absence of anything like a terminal moraine in the unglaciated valley, and the presence of such a moraine in the valley affected by ice.

2. The well cleaned out condition of the glacier basin, where large areas of bare rock are exposed, and the absence of such conditions in a landslide basin.

3. The even crest line of the deposits on the slopes of the glaciated valley and the uneven crest line of the areas of landslide.

4. The blocking of tributary valleys by lateral moraines and the absence of such blocking in the valleys affected by landslide.

Other differences in such valleys, not shown in the drawings, should also be noted.

1. The bare rock surfaces in glaciated basins commonly extend to the base of the bounding walls and sharpen the contrasts between the basin floor and the protecting cliffs. In the landslide basin the deposits are at the base of the cliffs from which they have come, or are topographically continuous with deposits at the immediate base.

2. The glaciated valley will have an open U-shaped form, while the others will be irregularly blocked by the landslides.

3. The glaciated vâlley is certain to show signs of deepening by ice, and in many such valleys the tributaries are left hanging. The unglaciated valley affected by landslides can not possibly show such signs, but, on the contrary, will be somewhat filled and choked by the slumping.

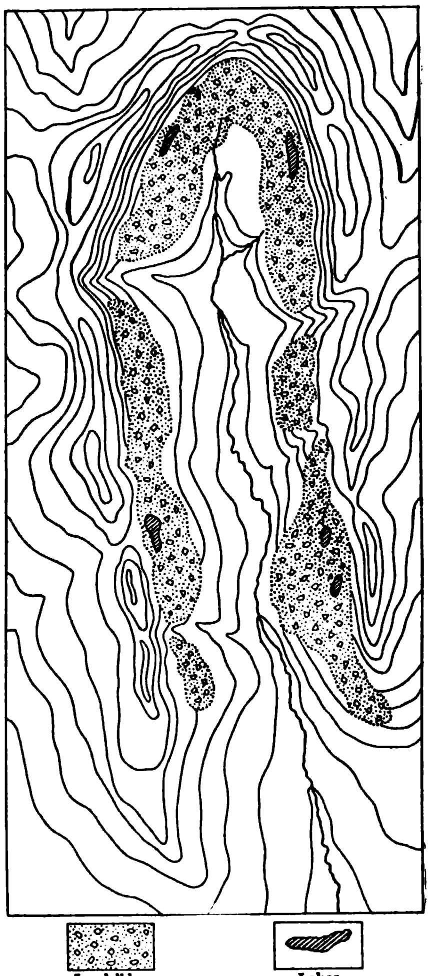


FIG. 10.—Diagrammatic sketch of a valley where landslides have affected the basin walls and valley slopes.

Of all the formations in this region the loose Tertiary conglomerate on the flanks of the Uintas has yielded most readily to gravity, and in some places both sides of interstream ridges have gone down in landslides until the core is not easily recognized. In some places hills have been so affected by slumping that lakes in landslide basins exist nearly to the crests of the hills.

SUMMARY AND CONCLUSIONS.

EXTENT OF GLACIATION.

From the map accompanying this report (Pl. IV) it appears that, at the period of the maximum extension of ice, glaciers covered by far the greater portion of the Uinta Mountains west of longitude 109° 40′ and a few extended beyond the mountains into the lower country north and south. The maximum extension of glaciation in an east-west direction was 82 miles, and in a north-south direction 42 miles. The total area covered by ice was somewhat over 1,000 square miles. The portions of the range that rose above the ice near the crest line were lofty peaks and narrow, rugged divides. On the flanks of the range the areas not covered by ice

Data concerning glaciers of Uinta Mountains.

Glaciers of earlier epoch.

Name of canyon.	No. of basin.	Size of catchment area.	Average elevation of floor of catchment area.	Average elevation of ice action in catchment area.	Average elevation of bounding walls of catchment area.	Average thickness of ice in catchment area.	Maximum thickness of glacier.	Length of glacier.	Lower limit of glacier.
		Sq. m.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Miles*	*Feet.*
NORTH SLOPE.									
Swifts	1	0.75	9,500	10,000	200	500	1,000	2.75	7,300
East Fork of Swifts	2	.50	9,200	9,500	100	400	500	1.50	7,800
South Fork of Weber	3- 5	2.50	9,100	9,700	400	500	800	4.25	7,400
Smith and Morehouse	6-12	9.25	9,800	10,200	400	400	700	11.50	7,200
The Weber system	13-18	10.75	10,000	10,600	600	600	1,500	13.50	7,500
West Fork of Bear	19	1.00	9,500	10,000	200	200	400	1.5	9,400
The Bear system	20-33	24.00	10,300	10,800	600	600	1,700	16.25	8,200
Basin 34 [a]	34	.50	10,000	10,500	400	300	500	2.5	9,800
The Blacks Fork system	35-44	19.00	10,500	11,200	800	500	1,300	22.00	7,600
East Fork of Smith Fork	45, 46	8.50	11,500	12,000	1,000	700	700	20.00	8,000
Henrys Fork	47-49	5.00	11,000	11,700	1,500	500	800	15.00	8,700
West Fork of Beaver Creek	50, 51	3.50	11,000	11,500	1,200	400	700	11.00	8,600
Middle Fork of Beaver Creek	52-55	5.00	10,500	11,400	1,000	700	700	9.00	8,500
Burnt Fork	56-58	9.00	10,500	11,500	1,000	500	700	13.50	8,100
West Fork of Sheep Creek [a]	59	4.00	10,500	11,300	600	500	800	6.25	8,500
East Fork of Sheep Creek [a]	60	4.00	10,000	10,500	500	600	1,000	7.50	8,000
Beaver Creek system [a]	61-64	6.50	10,000	11,000	700	600	600	6.00	8,200
Total for north slope	......	113.75	......	......	......	......	......	......	......
Average for north slope	......	6.69	10,170	10,788	664	500	......	9.65	8,165
SOUTH SLOPE.									
Basin 65 [a]	65	1.50	11,000	12,000	500	500	800	5.50	9,200
Ashley Fork [a]	66	6.00	10,000	11,250	1,000	900	1,000	11.00	9,000
Dry Creek [a]	67	5.00	10,700	11,250	250	500	1,000	11.00	9,000
White Rocks	68- 74	17.50	10,600	11,100	700	500	1,500	22.00	6,600
Uinta	75- 86	56.00	10,900	11,700	800	600	2,400	27.75	6,800
Basin 87 [a]	87	3.00	10,600	11,400	600	500	700	8.25	8,500
East Fork of Lake	88- 93	27.50	10,800	11,600	1,100	500	1,700	24.50	6,600
West Fork of Lake	94-104	36.00	10,700	11,400	800	500	2,000	25.50	6,600
Rock Creek	105-112	54.50	10,300	11,200	900	800	2,500	25.50	6,700
Du Chesne	113-117	24.00	10,200	10,900	700	500	1,700	21.00	7,400
Soapstone	118	.75	9,000	9,300	100	300	300	4.00	8,600
Provo system	119-123	29.00	9,500	10,500	500	700	1,500	15.50	7,500
Basin 124	124	1.50	9,500	10,100	500	500	800	4.50	7,100
Total for south slope	......	262.25	......	......	......	......	......	......	......
Average for south slope	......	20.17	10,369	11,054	646	544	......	15.84	7,661

Glaciers of later epoch.

Name of canyon.	No. of basin.	Size of catchment area.	Average elevation of floor of catchment area.	Average elevation of ice action in catchment area.	Average elevation of bounding walls of catchment area.	Average thickness of ice in catchment area.	Maximum thickness of glacier.	Length of glacier.	Lower limit of glacier.
		Sq. m.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Miles*	*Feet.*
Swifts	1	0.75	9,500	10,000	200	500	1,000	1.50	8,400
East Fork of Swifts [b]	2	......	......	......	......	......	......	......	......
South Fork of Weber	3	.75	9,300	9,700	700	300	500	2.50	7,800
	4, 5	1.75	9,000	9,700	400	600	650	3.50	7,800
Smith and Morehouse	6-12	9.25	9,800	10,200	400	400	700	7.75	7,500
West Fork of Weber	13	2.00	10,000	10,500	600	500	1,000	4.00	8,100
Middle Fork of Weber	14	2.50	10,000	10,800	800	800	1,500	6.00	8,100
Weber	15-17	4.25	10,000	10,700	650	600	1,500	7.25	8,000
Fish Lake	18	2.00	10,200	10,700	500	500	1,000	4.25	8,400
West Fork of Bear [b]	19	......	......	......	......	......	......	......	......
Hayden Fork of Bear	20, 21	6.75	9,900	10,700	600	700	1,200	10.50	8,600
Stillwater Fork of Bear	22-27	11.25	10,300	10,900	800	600	1,500	10.00	8,700
East Fork of Bear	28-33	6.00	10,500	11,000	600	500	1,700	11.50	8,700
Basin 34	34	.50	10,000	10,500	400	300	500	2.50	9,800
Blacks Fork	35-40	5.75	10,500	11,000	800	400	1,300	15.00	9,100
Middle Fork of Blacks Fork	41	1.50	11,000	11,500	1,000	500	700	8.25	9,100
East Fork of Blacks Fork	42-44	11.75	10,600	11,200	700	700	1,400	11.75	9,200
East Fork of Smith Fork	45, 46	8.50	11,500	12,000	1,000	700	700	18.50	8,200
Henrys Fork	47-49	5.00	11,000	11,700	1,500	500	800	9.50	9,400
West Fork of Beaver Creek	50, 51	3.50	11,000	11,500	1,200	400	700	10.00	8,900
Middle Fork of Beaver Creek	52-55	5.00	10,500	11,400	1,000	700	700	7.00	8,900
Burnt Fork	56-58	9.00	10,500	11,500	1,000	500	700	11.00	8,800
West Fork of Sheep Creek	59	4.00	10,500	11,300	600	500	800	6.25	8,500
East Fork of Sheep Creek	60	4.00	10,000	10,500	500	600	1,000	7.50	8,000
Beaver Creek system	61-64	6.50	10,000	11,000	700	600	600	6.00	8,200
Total for north slope	......	112.25	......	......	......	......	......	......	......
Average for north slope	......	4.88	10,243	10,869	721	539	......	7.91	8,530
Basin 65	65	1.50	11,000	12,000	500	500	800	5.50	9,250
Ashley Fork	66	6.00	10,000	11,250	1,000	900	1,000	11.00	9,000
Dry Creek	67	5.00	10,700	11,250	250	500	1,000	11.00	9,000
White Rocks	68- 74	17.50	10,600	11,100	700	500	1,500	17.50	7,250
Uinta	75- 86	56.00	10,900	11,700	800	600	2,400	20.00	7,600
Basin 87	87	3.00	10,600	11,400	600	500	700	8.25	8,500
East Fork of Lake	88- 93	27.50	10,800	11,600	1,100	500	1,700	16.50	7,900
West Fork of Lake	94-104	36.00	10,700	11,400	800	500	2,000	14.50	8,100
Rock Creek	105-112	54.50	10,300	11,200	900	800	2,500	20.00	7,600
Hades	113	1.75	10,000	10,700	900	400	1,200	5.00	8,000
Du Chesne	114-117	22.25	10,200	11,000	700	600	1,700	12.00	7,900
Soapstone [b]	118	......	......	......	......	......	......	......	......
Provo	119	16.00	10,000	11,000	1,000	1,000	1,400	7.00	8,500
North Fork of Provo and Bowlder	120, 121	7.00	9,200	10,600	500	700	1,500	8.00	7,600
Shingle	122	4.00	9,500	10,500	400	700	700	5.50	7,800
Basin 123	123	2.00	9,500	10,100	200	400	500	3.50	7,800
Basin 124	124	1.50	9,500	10,100	500	500	800	3.00	8,000
Total for south slope	......	261.50	......	......	......	......	......	......	......
Average for south slope	......	16.34	10,219	11,056	678	600	......	10.51	8,112

[a] Older drift not distinguished, but it is assumed that the earlier ice existed in the canyon.

[b] Not occupied by ice during the later epoch.

lay between the great canyons. These areas became broader and broader to the north and south, beginning as narrow ridges near the crest line, and broadening to plateau-like areas near the foothills. The portion of the range that rose above the snow fields associated with the glaciers must have been much less than that which rose above the ice. There is no way of determining how high the snow rested, but it is fair to assume that, aside from a few lofty peaks and narrow ridges, the range appeared as a long, white arch, rising about 7,000 feet above the country to the north and south, and suggesting, in form at least, a partial restoration of the great Uinta anticline.

Most of the catchment areas in which glaciers were formed are 10,000 feet or more above the sea. A few favorably located basins, between 9,000 and 10,000 feet, furnished ice. The lower glacier basins are all near the west end of the range, where the snowfall was presumably greatest. Near the eastern margin of glaciation there are many basins above 9,000 feet in elevation that did not contain ice. Three of the basins below 10,000 feet contained ice during the earlier epoch, but not during the later, indicating that a greater elevation was necessary for the formation of glaciers during the later than during the earlier epoch.

The map (Pl. IV, in pocket) and the table on page 66 bring out the general arrangement and dimensional symmetry of the glaciers. They extended southward and northward from the main crest line, reaching their greatest lengths in the central portion and decreasing both to the east and west. The longest glacier was 27½ miles long, the shortest independent glacier was 1½ miles long. During the earlier epoch there were thirty distinct glaciers. Most of these thirty glaciers may more properly be referred to as great systems, formed by the union of two to eight glaciers. During the later epoch, when the ice was not so extensive, fewer glaciers united, especially on the north slope, and the ice therefore then had a larger number of distinct termini. The total number of independent glaciers during the later epoch was thirty-nine.

If the great ice systems of the earlier epoch be subdivided and the tributary glaciers be counted independently the extent and number of the glaciers may be tabulated as below:

Length and number of glaciers in the Uinta Mountains.

Length in miles.	Number of glaciers.
20+	8
15-20	3
10-15	9
5-10	21
1-5	63

There were, therefore, 104 glaciers over 1 mile in length.

COMPARISON OF THE GLACIATION OF THE NORTH AND SOUTH SLOPES.

The catchment areas for the glaciers of the earlier epoch contained, on the average, nearly 7 square miles on the north slope, and a little over 20 square miles on the south slope. The lengths of the glaciers on the north and south slopes were, on the average, during the earlier epoch, 9.65 and 15.84 miles, respectively. During the later epoch the lengths of the glaciers on the north and south slopes were 7.91 and 10.51 miles, respectively. Only two glaciers on the north slope reached 20 miles in length, while on the south slope six exceeded that length. The lower limits of glaciation on the two slopes are shown in the following table:

Table showing lowest limits of glaciation in feet above sea level.

	Lowest limit during earlier epoch.	Lowest limit during later epoch.	Average lower limit during earlier epoch.	Average lower limit during later epoch.
North slope	7, 200	7, 500	8, 165	8, 530
South slope	6, 600	7, 250	7, 661	8, 112

These striking differences seem to be due fundamentally to the general structural conditions in the range. The fact that the crest line is nearer the north than the south margin of the mountains is of extreme importance. As a consequence the canyons on the north slope are shorter than those on the south slope. They descend more abruptly to those elevations where ablation overcame the onward movement of the ice. Furthermore, the basins on the north slope are in a zone of inclined strata, while those of the south slope are in the midst of essentially horizontal beds. These structural conditions account for the greater development of the catchment areas on the south slope. The widening of the basins progressed more rapidly in the region of horizontal strata than where the beds are inclined. The larger catchment areas and the longer canyons are sufficient to explain the more extensive glaciation on the south slope. These factors seem to have outweighed in importance the greater protection from the rays of the sun on the north slope and the more favorable location for the lodgment of wind-blown snows on the north. The angle of the sun's rays must have caused more rapid melting on the south side, and the prevailing southwest winds must have carried much snow from the southern catchment areas to the northern fields, and yet, with their immense basins and their long routes to low altitudes, the glaciers on the south slope far exceeded in magnitude those on the north slope.

GLACIAL EPOCHS.

The chief facts about the extent of the ice during the different glacial epochs are shown on the map (Pl. IV) and in the statistical table (p. 66). On the average the earlier glaciers advanced 5 to 10 miles farther down the canyons than did the later. In three basins there appears to have been ice during the earlier epoch and not during the later. In eight canyons where later drift but no earlier drift has been mapped it may be inferred that the later ice advanced as far as the earlier, obliterating the older records, or that a subdivision of the deposits has not been practicable. In every place where the older drift has not been recognized the field work has been greatly handicapped by dense forests, and in every place but one by the want of a good map. A comparison of the lower limits of glaciation during the two epochs is shown in the table on page 67.

The recognition of evidence of distinct glacial epochs among the mountains involves peculiar difficulties. Ice that descends a canyon is likely to obliterate all traces of earlier ice movement through the same course, particularly if the later ice advances as far as any earlier ice. The chances of finding buried drift in these restricted courses of the ice are therefore much poorer than in open country that was invaded by a continental ice sheet. The mere fact that the area in which data must be found to prove distinct epochs for a given canyon is very small enhances the difficulties in the problem and greatly reduces the chances of demonstration. Where the later ice did not advance so far as the earlier the problem may be easier. In fact, in every area where distinct epochs have been determined in the Wasatch or Uinta mountains, or in any other mountains, as far as the writer is aware, the earlier ice was more extensive than the later. In these areas the outer moraines have been subject to weathering and erosion for a longer period than the later or inner moraines. Distinct outwash deposits may also be associated with the two distinct systems of moraines. These outwash deposits must have a genetic relationship with the terminal moraines of the two epochs, and it may be presumed that the older alluvium or valley train suffered greater erosion than the younger.

The drift deposited by distinct glaciers in a mountain canyon at different times and places is, as a rule, of essentially the same composition; but if it contains some easily weathered material, such as fragments of coarsely crystalline rock, the difference in the amount of weathering or disintegration of the bowlders of separate deposits may clearly indicate a difference in the age of the deposits. Among the Wasatch Mountains the older and the younger moraines may be easily distinguished by the difference in the amount of weathering. Among the Uintas this kind of evidence is almost entirely wanting. The drift among the Uintas is composed largely of quartzite—in fact so largely that in most places it is difficult to find a specimen of any other kind of rock in the drift. The drift of certain canyons is composed entirely of quartzite, notably

the canyons at the eastern end of the area considered in this report, where distinct epochs have not been made out. Furthermore, the quartzite of the Uintas is so hard that the bowlders in preglacial conglomerates, derived largely from this formation, appear nearly as fresh as those in the youngest glacial deposits. The only difference that can be observed in the amount of weathering of the preglacial quartzite conglomerate and the quartzite moraines is that in the former there are more and larger bowlders that have been fractured, presumably by changes in temperature and by frost.

The determination of two epochs of glaciation among the Uintas rests chiefly upon these points:

1. There are two distinct systems of moraines in each of the main canyons.

2. The outer moraines are much more deeply eroded than the inner. In most canyons the outer terminal moraine has been entirely removed by erosion.

3. In some canyons, where an older lateral moraine rests on a slope above a younger moraine, the difference in the amount of erosion which each has suffered is very marked. Many tributary valleys that cross the upper moraine do not cross the lower, and therefore appear as blocked valleys in drift above the lower moraines, just as blocked valleys in rock appear above the upper moraines.

4. The greater erosion in the outer moraines is conjoined with greater deposition from its waste. In many of the canyons upstream from the older terminal moraine and below the younger terminal moraines immense alluvial fans have been developed by side wash.

5. Depressions in the older drift that were possibly the sites of lakes or marshes have commonly been filled with alluvium. Thus the older moraines now contain but few lakes and marshes, while the younger moraines contain many.

6. In three canyons there are records of ice of only an earlier period, but none of the later.

7. In some localities two distinct valley trains have been determined, one associated with the outer and the other with the inner moraines.

The alternative interpretation of the glacial deposits in the range is that the so-called younger moraines are recessional moraines deposited by the same ice that built up the outer, older ridges. The marked differences in the age of these two series of moraines make this interpretation unsatisfactory. The time necessary for the removal of the outer terminal moraine and much of the outer alluvium must have been many times—perhaps ten or twenty times—as long as the period that has elapsed since the final melting of the ice.

THE INFLUENCE OF TOPOGRAPHY ON THE ICE.

It has already been pointed out that the formation of the Uinta glaciers has been controlled by the size and elevation of the catchment areas. It is equally clear that the movements of the ice were in large measure dependent on the topography of the range. At some places the divides were covered by ice, and yet at every such place the form or slope of the surface below the underlying rock divide determined its course or motion, causing movement in opposite directions in a continuous ice mass. In the catchment areas the movement was in general toward the canyon. From certain catchment areas the ice was forced to pass around isolated peaks and ridges that rose above the ice as nunataks. In some places the ice from a single basin was divided and forced to move down different canyons on the same slope. The canyon ice was here and there forced by some projecting rock spur to swing to one side or the other. At constricted portions in the canyon the ice responded somewhat as rivers do and worked its way through the narrows, to deploy as soon as the walls of the canyon permitted. At several points the canyon ice was required to turn at a right angle in order that it might move down the valley.

THE INFLUENCE OF ICE ON THE TOPOGRAPHY.

While the ice responded to topography and in large measure was controlled by the physical features of the range, yet at the same time it was modifying the forms encountered, changing the shape of the great canyons, and building new forms.

Before the first Pleistocene snows fell on the Uinta Mountains the heads of the great canyons, it may be fairly assumed, were narrow V-shaped notches, most of which reached nearly to the crest line of the range. The first ice was formed in these narrow canyon heads, and the earliest movement must have been down canyon. As the ice at the heads of the canyons increased in thickness there came to be a notable movement down the sides of the gorges, concentrating the ice in the canyons and causing further movement downstream. With the movement of the ice on the slopes in these miniature catchment basins loose débris was carried downward and the basins were both widened and lengthened. About the margin of these early ice fields weathering and ice plucking was in progress, such work as is going on to-day at the base of the Bergschrund.[a] In this way the catchment areas were increased in size and changed into cirquelike forms. Work of this kind has been described by Penck[b] as follows:

Glaciers not only exercise a sapping action along their sides, but also at their very heads, if they are here overlooked by rock cliffs. There is always a marginal crevasse, called in German Randspalte or Bergschrund, which separates the moving ice from the rocks which overlook it. The material loosened here by weathering falls down from the rock walls into this crevasse and arrives at the bottom of the névé, where it is pushed forward by the mass grinding the bottom of the glacier. By this not only the formation of screes around the glacier is hindered, but also the surrounding cliffs are constantly attacked, for the erosive action begins just at their foot and saps them. Glaciers, therefore, which are formed on slopes in broadly open valley basins, surround themselves finally by cliffs, which are pushed backward much as are the cliffs around the gathering basin of a torrent.

Just south of the main crest line weathering and plucking work of the ice went on under the most favorable conditions. There the strata are essentially horizontal and sufficiently variable in hardness to favor rapid disintegration. The giving way of the softer beds left the overhanging harder strata exposed. Cliff and talus slopes developed, and the ice, working sideward and headward, or in general outward, around the margin of the ice field, would carry these steps or benches farther and farther back. In some places a very resistant layer of quartzite served as a base to which the quarrying work of the ice went on over several square miles. Then another resistant layer, 10, 20, or even 200 to 300 feet higher, would become the floor of the quarry. The work, therefore, went on somewhat in the fashion in which men widen and deepen quarries in similar formations. Many abandoned benches remain to-day about the margins of the great catchment areas.

Coincident with the widening of the basins there was a narrowing of the divides between the heads of the canyons and a narrowing of the main crest of the range. Some of the divides (see Pl. II, *A*) were so reduced in width that it is dangerous to try to walk along them. Others were surmounted and greatly reduced in height by the ice. The main crest line was sharpened, and the peaks were made more prominent.

In the canyons the great change, so often referred to in the detailed descriptions, was the development of broad U-shaped troughs. The preglacial forms were obliterated. The canyons were widened and deepened. In this process many tributaries were left as hanging valleys, with their lower ends several hundred feet above the main stream. The canyon walls were smoothed off as far up as the ice rested. Preglacial erosion lines and the asperities common to the slopes of unglaciated canyons were rubbed off. In the bottom of the gorges, on the canyon walls, and in the basins, the glaciers built up new topographic forms. They added to the physical features of the range numerous morainic ridges and many square miles of hummocky or rolling drift topography. The extensive terraces extending downstream from the terminal moraines are remnants of valley trains developed by waters issuing from the glaciers.

POLISHED AND STRIATED SURFACES.

Polished and striated surfaces of bed rock are restricted almost exclusively to the basin regions. In areas where the drift is scarce striæ, grooves, polished surfaces, and roches moutonnées are common. Square miles of bed rock are exposed in the higher portions of the range, where the signs of ice action are beautifully shown. In many of the passes in the main crest line glaciated surfaces appear. Striæ have been found as high on some of the peaks as any

[a] Johnson, W. D., Jour. Geology, vol. 12, 1905, p. 573.

[b] Penck, A., Jour. Geology, vol. 13, 1905, p. 15

other signs of ice action, and about the marginal portions of the basin regions ice action is often recorded both in glaciated surfaces and in ice-gouged basins in the hard quartzite rock. A few striated rock surfaces have been found deep in the canyons and on benches or shoulders on canyon walls.

INFLUENCE OF GLACIATION ON DRAINAGE.

Hundreds of glacial lakes and marshes, especially in the basin region of the range, indicate that the drainage has been greatly modified by the ice. Among these mountains there are now more than 550 glacial lakes. In nearly every basin waters are ponded by morainic deposits or are retained in rock basins gouged out by the ice. A few tributary streams in unglaciated valleys have been ponded by the lateral moraines of a main canyon. Terminal and recessional moraines in some canyons have blocked the courses of the main streams and caused the formation of chains of lakes. The glacial lakes vary in their longer diameters from a few rods to 1½ miles. Most of them are less than half a square mile in extent.

At the close of the glacial period such chains were much more common than they are to-day, but in their places are chains of meadows, separated from one another, as the former lakes were, by morainic ridges. A few streams are to-day partly ponded by morainic dams. In these dams the drift is not sufficiently compact to hold the waters until they rise and overflow; they seep through the loose deposits and issue as springs a short distance down the canyon.

The hanging valleys may also be mentioned in this connection, for they indicate marked changes in drainage. Scores of tributary streams in such valleys are now out of adjustment with the main streams. Falls and rapids have been caused which many more centuries of work may not remove from the stream courses.

POSTGLACIAL WORK.

Since the ice last left the Uinta Mountains the work of weathering and erosion, except in certain inner gorges on the south slope, has been trivial and insignificant. The moraine material of the later epoch is but little disintegrated, and most of the streams are yet engaged in cleaning away the glacial débris from their courses. Near the summits changes in temperature, frost, gravity, and moving névé have so combined as to produce extensive accumulations of talus about the margins of the basins. The inner rock gorges in the main canyons of the south slope have already been described in detail. They are the most striking postglacial features in the range. On the average they are 50 to 80 feet deep and 5 to 6 miles long. They are limited to upper portions of the canyons and do not appear to be due to a general rejuvenation of the streams. They are in those portions of the canyons where deepening by the ice was greatest, and therefore where the stream bed would naturally be relatively low. The favorite explanation of these gorges is that they are due to a slight postglacial uplift along an east-west line about 10 miles south of the axis of the range.

GLACIATION AND IRRIGATION.

The present streams from the Uinta Mountains, if under control, would furnish enough water to irrigate hundreds of square miles in the lower country. If the glacial lakes, of which there are over 500, were connected directly with the streams and used as reservoirs, the irrigating capacity of the streams would be immensely increased. An inexpensive dam would control the waters of nearly every one of these natural reservoirs, and many such dams could be built of material near at hand. The forests supply an abundance of timber and the glacial drift an abundance of loose material. The waters of most of the lakes could be easily increased a few feet in depth, and thus be used to irrigate many additional acres of land. Simple efforts have been made to control the waters of a few such lakes. China Lake, in the East Fork of Smith Fork, now serves as a reservoir. At the south end of Lake Washington, in the Provo Basin (No. 119), a dam was built which, if effective, would have raised the water in the lake a few feet and reserved a large supply for the later part of the growing season. The dam is now broken and the outlet of the lake is being gradually lowered by the outflowing waters. The outlets of

many former glacial lakes could be closed and new reservoirs thus made. Many of the younger terminal moraines in the canyons have but narrow notches cut through them. By closing these postglacial notches extensive reservoirs could be formed in the lower portions of the canyons.

Most of the irrigable land south of the mountains is now owned by the Ute Indians, who carry on some agricultural work, but only near the streams, where the land is very easily watered. The country north of the range is inhabited by ranchmen, who find it more and more necessary each year to raise fodder for their stock. The land is being rapidly taken up and fenced off for private ranges. In this country irrigation is practiced somewhat extensively, and yet little or nothing has been done to control the waters in the basin region or to develop new reservoirs lower down in the canyons. The streams are steadily lowering the outlets of many of the lakes and both widening and deepening the cuts through the moraines in the canyons, so that the amount of work necessary to get control of the water supply in the range increases from year to year.

GLACIATION OF THE WASATCH MOUNTAINS.

LOCATION AND EXTENT OF AREA.

The portion of the Wasatch Mountains considered in this report extends from latitude 40° to latitude 41°. The maximum width of the range, where visited, is about 20 miles. The total area studied contains nearly 1,000 square miles and is included within the Salt Lake quadrangle of the topographic atlas of the United States. Pl. X is a copy of a part of the Salt Lake sheet, on which the extent of glaciation is indicated.

GENERAL PHYSIOGRAPHIC FEATURES OF THE REGION.

The main crest line of the Wasatch Mountains extends in a general north-south direction and stands 4,000 to 6,000 feet above the level of the Bonneville Basin[a] to the west. The approach to the mountains from Great Salt Lake is by a series of steps or benches representing the ancient Lake Bonneville, rising to its uppermost shore line, which is recorded on the mountain slopes about 1,000 feet above the level of the present lake. Above this shore line the rocky faces of the mountains, at most places precipitous, rise 500 to 600 feet. From a distance the features of the ancient shore lines dwindle into insignificance and the bold and rugged mountains appear to rise abruptly out of alluvial plains.

The east slope of the range is more gentle than the west. The contours on this side are softened, and the slopes are generally well clothed with vegetation.

Between the Wasatch and the west end of the Uintas lie a number of waste-filled basins, surrounded by mountains of softened contour, 8,000 to 9,000 feet in elevation. These basins appear on Pl. X as Provo Valley, Parleys Park, and Kamas Prairie.

The main crest line of the Wasatch Mountains is near the eastern border of the range. This line is serrate, consisting of a number of peaks, most of which rise to elevations of about 10,000 feet. Clayton Peak, now locally known as Mount Majestic, is the highest peak in the area studied, having an elevation of 12,000 feet. West of the main crest line, extending from latitude 40° 10′ to 40° 25′, there is a minor north-south crest, much of which rises above 10,000 feet. This minor crest had an important influence in determining the positions of many glaciers. There are two prominent east-west divides, one between Little and Big Cottonwood canyons, and the other between Little Cottonwood and American Fork, which also had much to do with the distribution of the glaciers in the region. (See Pl. X.)

Since the main crest line is near the eastern border of the range, the valleys of the west slope are much longer than those of the east. Little and Big Cottonwood canyons, on the west side, are 12 and 15 miles long, respectively, while the canyons of the east slope vary from 3 to 6 miles in length.

The lofty peaks of the range that are made of crystalline or highly metamorphic rock are of rugged, pinnacle-like form; those that are carved in horizontal sedimentary beds are of pyramidal form, with alternating cliffs and talus slopes. These two types may be brought into sharp contrast by comparing Lone Peak with Timpanogos Peak. Summits that do not reach above 9,000 feet, and even some that reach nearly 10,000 feet, are rounded and softened in contour, for at such altitudes disintegration has produced heavy soils.

The topographic features of the region which are due to glaciation will be discussed later in the report.

[a] Gilbert, G. K., Mon. U. S. Geol. Survey, vol. 1.

RECORDS OF EXTINCT GLACIERS.

The work of the ancient glaciers in this region will be described in detail in geographic order, the description beginning with the glaciers at the south, about Spanish Fork Peak, and ending with those of the Farmington region, at the north margin of the Salt Lake quadrangle. The catchment basins on Pl. X have been numbered in the order in which they and their associated valleys will be described.

SPANISH FORK PEAK.

Spanish Fork Peak is near the southern margin of the Salt Lake quadrangle (Pl. X) and reaches an elevation of 10,000 feet. There are no large catchment basins about it. The head of a small canyon on the north slope, at an elevation between 8,000 and 9,000 feet, has been affected by snowslides and névé, but no true glacier seems to have existed there.

PROVO PEAKS.

On the southeast slope of Provo Peaks there are three small basins at an elevation of 9,000 feet which contained miniature glaciers. These basins are at the heads of what are known locally as Bartholomews and Whitmores canyons, which are tributary to the left fork of Hobble Creek.

The Provo Peaks glaciers were less than 2 miles long, and the moraines which they left are but 50 to 75 feet high. The moraines are composed of quartzite and sandstone bowlders, mingled in a sandy matrix. The ice action consisted in moving a part of the loose material from the heads of the basins a short distance down the canyons. Little erosion on bed rock was accomplished. Among the drift deposits in these basins there are two small lakes.

PROVO CANYON AND ITS TRIBUTARIES.

The main Provo Canyon, where it crosses the Wasatch Range, was not occupied by ice, although two of its tributaries, South Fork and North Fork, held glaciers of considerable size.

The valley of South Fork is remarkable in that the slope facing north has been softened by glacial wear and a veneering of drift, while the slope facing south is heavily covered with angular talus blocks, above which are the rugged and fantastic forms due to weathering. The stream thus flows between two areas that present strikingly different types of topography. Except at one place no drift was found on the north side of the stream.

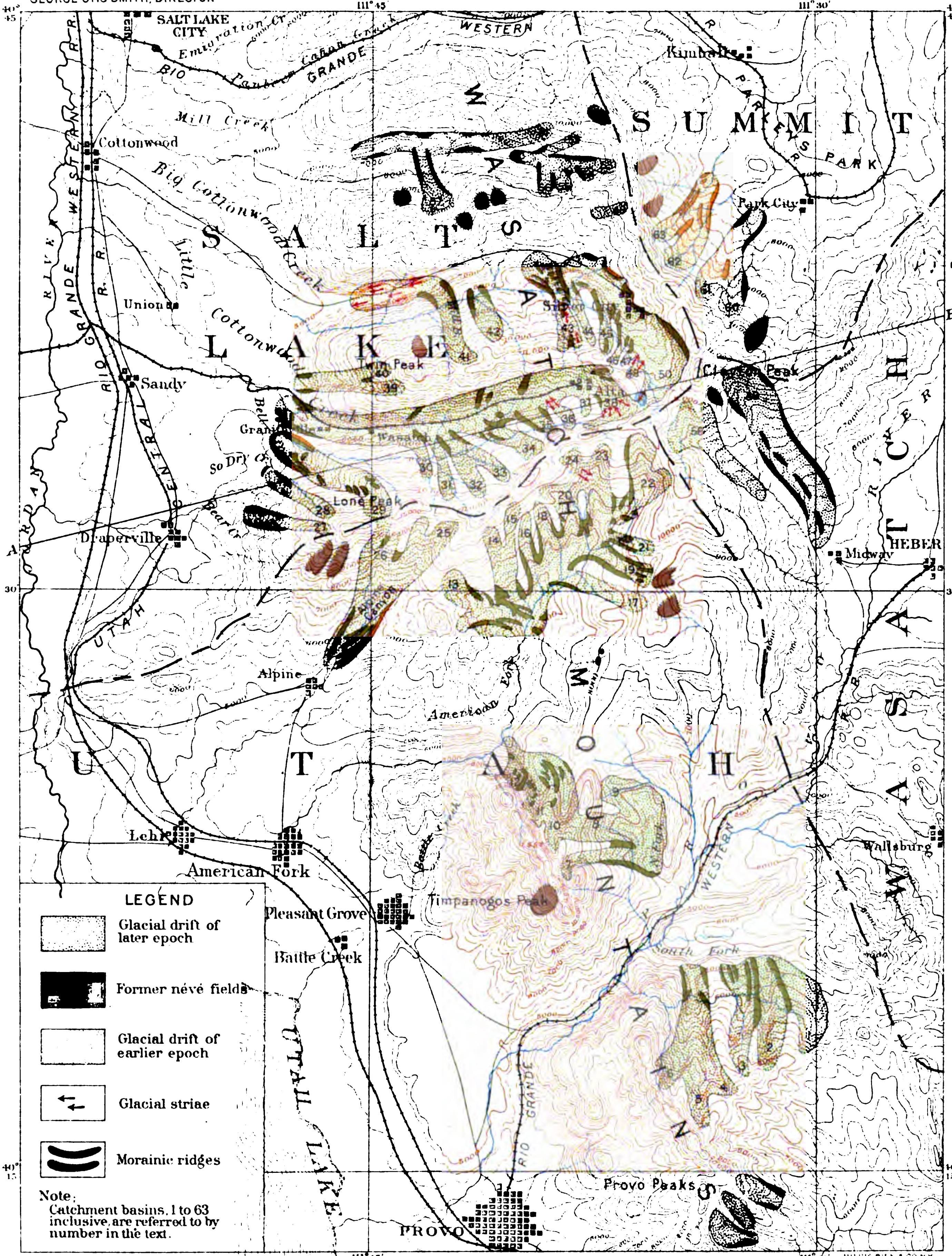
The ice that brought the drift to the south side of this valley, but failed to move farther, came from six cirquelike basins (1 to 6, Pl. X) on the northeast, or leeward side, of Provo Peaks. These basins stand at an elevation of about 9,000 feet and, being protected by the high peaks to the southwest, are favorably located for the lodgment of snow.

The ice that formed in basins 1, 2, and 3 soon joined to form one glacier, which was somewhat vigorous in its action through the upper portion of its course, but, losing strength rapidly, deposited large quantities of drift in its lower course, building up moraines 150 to 200 feet thick at its terminus, on the south slope of the valley of the South Fork. The lateral moraines left by this glacier are yet well preserved, but the terminal moraine and a recessional moraine about 1 mile upstream from the terminal moraine have been partly removed by erosion. The larger stones in the drift of this valley are of quartzite, sandstone, or limestone, and the finer material contains more sand than clay. At its maximum extension the ice descended to an elevation a little less than 5,000 feet.

The ice that formed in basins 4, 5, and 6 moved as three independent glaciers, each about 1½ miles long, and then, uniting, moved northward and descended to an elevation of about 5,000 feet on the south slope of the valley of the South Fork. The maximum extension of the ice from the heads of the basins was nearly 4 miles and the width of the ice front was about 2 miles. The medial or interlobate moraines built up by the ice from these several basins are conspicuous features, rising 100 to 200 feet above the streams that border them and maintaining a ridgelike continuity for about 2 miles below the junction of the glaciers. The gradient over which this ice moved is not great, a fact that helps to account for the prominence of the

U S GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER NO. 61 PL. X



JULIUS BIEN & CO. N.Y.

Triangulation and topography by the King and Powell surveys

PORTION OF SALT LAKE QUADRANGLE, UTAH
Showing distribution of glacial formations

Rollin D Salisbury, Geologist in charge
Glacial geology by Wallace W Atwood

Scale 1:250000

0 1 2 3 4 6 8 10 12 miles

0 2 4 6 8 10 12 14 16 kilometers

Contour interval 250 feet
1907

work of deposition and the meagerness of the work of erosion. The larger stones in the drift deposited by this ice are chiefly of quartzite, though fragments of limestone and sandstone occur.

The branches of the South Fork that were not glaciated head among peaks which stand at an elevation of about 8,500 feet, and which failed to collect snow enough to form glaciers, and therefore have an unmodified erosion form.

North Fork of Provo River received its supply of ice from basins 7, 8, and 9 (Pl. X). Basins 7 and 8 are cirquelike in form and are located on the east side of Timpanogos Peak at an elevation of about 10,000 feet. The glaciers from these basins moved vigorously through their upper courses, clearing away the loose material, but as the ice reached lower altitudes abrasion became less active, probably because of excessive melting, and deposition more important. The heavy moraines left by these small tributary glaciers turn southward at points where the ice that formed them met the ice from basin 9 and moved down the valley of North Fork of Provo River.

The united ice from these basins descended a little below 6,000 feet and there built up moraines which are yet well preserved. These moraines are made up chiefly of quartzite and limestone bowlders, which are so little weathered that they seem to belong to the deposits of the later glacial epoch.

AMERICAN FORK CANYON.

Strictly speaking, the name American Fork applies to the 5 miles of the canyon below the junction of North and South forks. In this portion the valley is V-shaped and extremely rugged (see Pl. XII, *A*), and evidence of glaciation is entirely wanting. The contrast between this rugged V-shaped gorge and the softened U-shaped form farther upstream is one of the most striking features associated with the glacial phenomena of this canyon.

SOUTH FORK OF AMERICAN FORK.

The system of moraines northeast of the Timpanogos range indicates that a number of glaciers formerly occupied this area. The location of the moraines shows that some ice from the Timpanogos cirques moved down a tributary of the Provo and some down South Fork of American Fork. One of the moraines of this series forms a continuous, sharp ridge, as symmetrical in form and graceful in curves as a well-built railway grade, and makes a decided turn down the valley of South Fork of American Fork. The moraines consist of material gathered from the great series of sandstones, limestones, quartzites, and shales that compose Timpanogos Peak, shown in part in Pl. XI, *B*. This same view also shows a portion of basin 10, on the northeast face of Timpanogos Peak. The talus about the margin of the basin is of postglacial origin and is rapidly accumulating. The basin floors are in part masked by morainic deposits, but are in part swept clean of all loose material. Where the bed rock is exposed glacial striæ, grooves, and polishing are common. The descent from the basin is over a series of steps, bordered by nearly vertical walls, like that from the uppermost basin in Pl. XI, *B*, down to the main catchment area shown in that view. Such vertical faces were undoubtedly the scene of a great deal of plucking by the ice, and consequently a source of some of the material gathered by the glaciers. The plucking and gathering of material caused the retreat of the escarpments and a widening and lengthening of the main catchment basin.

Below the collecting areas the movement of the ice was less vigorous and the depositional work predominated over erosion. In the lower portions of the valleys below these basins are the heavy moraines already referred to.

NORTH FORK OF AMERICAN FORK.

In the North Fork, 2½ miles above the junction with the South Fork, morainic deposits appear. Below that point there is some fluvioglacial material, but no evidence of ice occupancy. Above that point, upstream to the lower margin of the catchment basin, a distance of about 6 miles, the valley contains heavy deposits of glacial drift.

The tributary valley below basins 13, 14, and 15 (Pl. X) contained a large glacier that moved southeastward to the main valley of North Fork. This glacier was fed by three glaciers, each over 2 miles in length, heading in the lofty cirques in the divide between North Fork and Little Cottonwood. The moraines developed by these three glaciers and by the greater glacier formed by their union are prominent topographic features. They appear as a series of roughly parallel ridges rising 50 to 100 feet above their surroundings, with minor spurs which advance into the tributary valleys in the manner of recessional moraines. The arrangement of the moraines is shown on Pl. X. The material of these moraines was derived chiefly from the light-colored granite about 4 miles east of Lone Peak, though the eastern portion contains an admixture of reddish sandstone derived from basin 15.

In a ravine cut by the tributary heading in basin 13 and about a quarter of a mile from the North Fork, the following section through the glacial drift and into the underlying material occurs: At the surface 4 to 6 inches of soil formed since the last retreat of the ice; below the surface soil a sheet of till 8 to 10 feet thick, composed chiefly of fresh or unweathered granite; beneath the drift an old soil 6 to 18 inches thick; below the buried soil ancient stream alluvium. The buried soil is black, from an abundance of humus, and is so disturbed that at places it bulges up and appears to be crushed. These phenomena appear to be due to the advance of the débris-laden ice, for on the stoss side of each little fold there is lodged a great bowlder. The alluvium examined was exposed to a depth of 20 feet and throughout that depth had a dark-red color, which set it off in sharp contrast to the white granite drift above. Furthermore, the alluvium contains an abundance of dark-colored porphyritic rocks, which are entirely absent from the till. The porphyry bowlders contained in the alluvium came from a direction other than that from which the ice moved and probably from the southeast, where such rocks outcrop. The alluvium is somewhat stratified.

The overlying till sheet has a rolling topography and was traced continuously north and northwest to the great cirques bounded by white granite peaks. From these cirques no porphyries such as occur in the alluvium could have come.

Basin 16, located on the south slope of the divide between the North Fork and Little Cottonwood, has an elevation of 9,000 feet, and furnished a small tributary glacier about 2 miles long. The glacier originating in this basin moved southward over a gentle gradient for more than 2 miles before joining the glacier in the North Fork. The low gradient over which so small a glacier moved is sufficient to account for the absence of marked glacial erosion in its course. The ice gathered up the loose material in its upper course, and deposited on the slopes and floor of its lower course that part which was not contributed to the main glacier.

The lower portion of this tributary valley except in its bottom, where the stream has cut a narrow gorge, is covered with drift that is little modified by erosion. The morainic material consists of sandstone, quartzite, and limestone bowlders, derived from formations outcropping in the valley, embedded in a matrix such as would result from the grinding up of such materials.

The floor of basin 17 has an elevation of about 9,000 feet, and served as the collecting area for a narrow glacier that moved westward for nearly 3 miles before joining the main glacier of North Fork. This glacier was not very active, and failed to lower its bed to the level of the main valley by about 200 feet. The gorge it occupied is therefore a hanging valley, and the stream flowing in it descends by rapids and cascades to the North Fork.

The moraines in this valley are distributed over the greater part of its length, though less conspicuously in the upper portions. The heavy forest here obscures their forms, but in the lower portion of the valley a pair of lateral moraines is sufficiently well defined to be mapped. Most of the morainic material is limestone and the residuum of limestone, with some sandstone intermingled.

Basin 18 is in size and position similar to basin 16, and furnished a small tributary glacier, about 1½ miles long. This glacier joined the ice in the North Fork a short distance below the present location of Forest City. This tributary glacier was not very vigorous, carrying away from the basin and upper portions of its course only the more easily eroded material. A part of the material thus gathered must have been carried along by the main North Fork glacier,

A. LATERAL MORAINES AT WEST MARGIN OF WASATCH RANGE, ASSOCIATED WITH BELL AND LITTLE COTTONWOOD CANYONS.

B. TIMPANOGOS PEAK, AT THE HEAD OF BASIN 10.

Showing approximately horizontal strata. Elevation of summit, 11,957 feet.

but a large part was left in the lower portion of the tributary valley, partly as lateral moraines, some as much as 200 feet above the stream bed, and partly as irregular deposits in the valley bottom. In composition this drift does not differ from that in the neighboring tributary valley next west. Sandstone, quartzite, limestone, and finer material derived from the same formations characterize the deposits. The gradient over which this tributary glacier moved was not very great, a fact which helps to account for the slight erosional work accomplished here by the ice. Since the final melting the tributary stream from basin 18 has cut a sharp V-shaped gorge in the morainic deposits.

The tributary glacier from basin 19, joining North Fork near Forest City, left a series of particularly well-developed moraines. Massive lateral moraines border the stream on both sides, recessional moraines cross the valley at intervals, and medial moraines are lodged on the valley bottom, lying parallel with the general course of the stream. Three cirquelike catchment basins furnished snow and ice to this glacier, and where the ice from two cirques met medial moraines were formed, which, on the melting of the ice, were left as ridges in the midst of the valley. These drift ridges now appear as extensions of the intercirque spurs.

From basin 20, located on the south slope of the main divide between the North Fork and the Little Cottonwood, a small glacier descended southward for about 2 miles and joined the glacier of North Fork. At the junction of the tributary with the main glacier, the ice in the tributary valley must have been at least 200 feet thick, as is shown by the position of the lateral moraines in the tributary valley. This glacier cleaned away most of the loose material from its basin, obliterated details of stream erosion and weathering on its bounding walls, and gave to the valley a U-shaped form. On the retreat of the ice front a recessional moraine was left about one-half mile above the junction of the tributary stream with the North Fork, and at other points deposits were left which give to the present valley floor an irregular surface, into which a small postglacial gorge has been cut. The drift in this valley is composed chiefly of quartzite and sandstone derived from the basin region, but considerable limestone gathered in the lower portion of the valley appears in the moraines near its mouth.

Basin 21 is 2½ miles east of Forest City, near the main crest line of the range, at an elevation of nearly 10,000 feet. Such a location was favorable for the formation of a glacier, and had this basin been larger and more cirquelike, with high protecting walls, it would have furnished a much larger glacier. The present conditions in the valley, however, indicate that the ice action was not vigorous. The tributary glacier, which moved but a little more than 1½ miles before joining the main glacier of North Fork, failed to clean away all of the loose material from the upper portion of its course. The moraines, composed chiefly of limestone and limestone residuum, with a small amount of sandstone material, are positive evidence of glaciation; but striated surfaces of bed rock, roches moutonnées, and the deepening of the valley by ice gouging or other evidences of vigorous glacial erosion, are absent. Some of the moraines in this valley are ridgelike in form and rise 50 to 75 feet above their surroundings, but a large portion of the glacial drift is irregularly distributed over the valley bottom.

The tributary valley heading in basin 22 contained a glacier nearly 3 miles long and about 100 feet thick at its lower end. The upper end of this valley is well cleaned out, but its lower part is partially filled with moraines. From the arrangement of the moraines at the lower end of this valley it would seem that the tributary glacier retreated somewhat before the ice in the main valley had receded above the junction. The lateral moraine that crosses the mouth of the tributary was not affected during its formation by the tributary ice, the end of which, from the position of a recessional moraine, seems to have rested at this stage a few rods up the tributary valley. (See Pl. X.)

In basin 23, near the head of the valley, there is a lake fully 400 feet above the junction of the tributary with the main stream. The descent from the lake is precipitous, and the tributary may properly be called a hanging valley. The difference in elevation between the main and the tributary is due, in part at least, to greater ice gouging in the main valley.

The main catchment basin of North Fork (No. 24) is so filled with talus that at the first glance it does not seem to have been glaciated. Striæ were found, however, on the quartzite

rocks on the sides and bottom of the basin and on the bowlders in the gorge. From the location of the striæ and the elevation of certain benches from which all loose material had been cleaned off, it was obvious that ice at least 500 feet thick once moved from the basin down the main gorge. The stream has just succeeded in cutting away the drift in the head of the valley and is now flowing on striated surfaces of the bed rock. The marks of glaciation in this basin are weak, and the amount of talus developed since the ice left is great as compared with those in other large catchment basins in this region.

Below basin 24 the valley of North Fork is broad and U-shaped. At places the stream has developed flats 100 to 200 feet wide. Great moraines, 400 to 500 feet above the stream, are lodged on the valley slopes. Sometimes two or three ridgelike benches are seen on the side hill, probably indicating different positions of the ice during the period of decadence. Near Forest City the heavy drift filling is so distributed as to form terraces. The drift of the lower terraces may have been somewhat worked over by water. but the main or higher terrace is of till and has a characteristic till topography.

A few rods below Forest City, in the main valley of the North Fork, there is a great mass of till of a peculiar and uncommon type. (See Pl. XII, *B*.) The ice must have pushed against a hill of limestone and crushed and tumbled the angular blocks of rock into a mass that now suggests a great breccia with the cement gone. The angular blocks have been moved but not worn. Occasionally a rounded drift bowlder, brought from some point farther up the canyon, is found in the midst of this till. This peculiar formation extends for more than a quarter of a mile along the right bank of the stream and is from 10 to 30 feet thick.

Near the mass of angular till the main stream has developed a beautifully symmetrical V-shaped gorge 100 to 150 feet deep in the drift. At other points in the valley of the North Fork exposures of drift 50 to 100 feet thick are seen. but at no point was more than 150 feet of drift filling determined.

ALPINE OR DRY CREEK CANYON.

A valley descends from basins 25 and 26 in the region of Lone Peak and opens out at the village of Alpine. On King's map[a] this valley is marked "Dry Creek," but locally it is now known as Alpine Valley or Canyon.

The white granite walls about the basin are smoothed and the loose material of the slopes have been largely cleaned away. Roche moutonnée surfaces are common about the head and on the slopes of the valley. The catchment basin and the valley below show signs of vigorous ice action, resulting from a gradient of more than 1,000 feet per mile, over which the glacier descended.

The lower part of the valley contains a large amount of drift. Lateral moraines lie high on the slopes, and the outer and upper two on either side appear much older than those within and below (fig. 11). Their greater age is shown not only by their position but by the relatively large amount of erosion and disintegration which they have suffered.

The material of the outer moraines is so disintegrated as to form a thick mantle of soil, while the inner and lower deposits show an insignificant amount of postglacial weathering. Many of the crystalline rocks on the surface of the outer moraines have crumbled. Others are about ready to crumble and fall to pieces if struck with the hammer. The surface bowlders of the inner series of moraines are so fresh that striæ are preserved on their surfaces. They appear not to have been in the least affected by weathering.

The contrast in age between the two series of moraines is also shown by the more numerous and deeper erosion lines in the outer series. The more recent deposits show but insignificant gully lines, while the outer moraines are considerably dissected.

These facts, strengthened by similar data from other canyons, justify the following conclusions:

(1) That there were at least two distinct glacial epochs in the region; (2) that, so far as thickness of soil may furnish a basis for estimating time, the interglacial period was much

[a] U. S. Geol. Explor. 40th Par.

A. UNGLACIATED PORTION OF AMERICAN FORK CANYON.

B. ANGULAR TILL ON NORTH FORK OF AMERICAN FORK.

longer than that which has elapsed since the last retreat of the ice; (3) that during so long an interglacial period a notable amount of erosion must have taken place; (4) that the ice of the earlier period was more extensive than the ice of the later period.

The Alpine Valley glacier of the earlier epoch advanced over a mile beyond the Bonneville shore line. (See fig. 11.) The central portion of the older and outer terminal moraine has been cut away, so that only a line of bowlders remains to mark the location of the ice front. During the last epoch the ice advanced but a few hundred feet into the Bonneville Basin. The terminal moraine of this epoch is fairly well preserved and appears as a ridge 20 to 40 feet high. The relation of the glacial epochs to the stages in the history of Lake Bonneville will be considered later, after additional data have been considered.

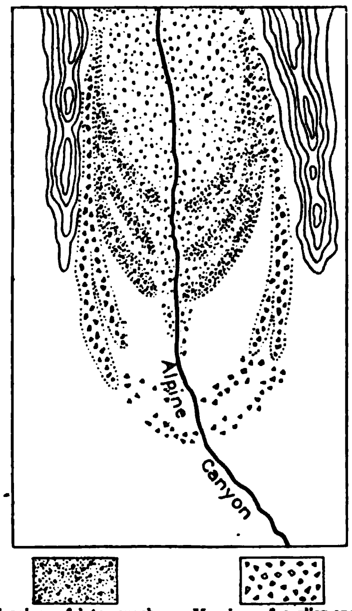


FIG. 11.—Sketch map of the morainic ridges near the mouth of Alpine Canyon.

Just west of the Alpine Basin on the south slope of the mountain are two small cirques which certainly held considerable névé fields and may for a time have contained small glaciers.

BEAR CREEK CANYON.

The U-shaped form of this gorge and the great masses of drift lodged at its mouth and on the valley slopes are sure indications of former occupancy by ice. (See fig. 12.) The drift material is largely white granite and contains bowlders 10 to 15 feet in diameter.

At the mouth of the canyon glacial drift lies 200 feet above the Bonneville level, indicating that a very considerable thickness of ice descended to the shore line. The moraines left in the lake basin appear now as ridges 10 to 40 feet high. The catchment basin of Bear Creek canyon (basin 27) is a large open cirque on the west side of Lone Peak, at an elevation of 10,000 feet.

The two postglacial and post-Bonneville faults shown in fig. 12 are well marked in the moraine material, where they expose fresh faces of the drift. The fault scarps are now 20 to 30 feet high, the eastern being the higher. Since the Bonneville waters receded Bear Creek has cut a gorge 10 to 15 feet deep in the drift.

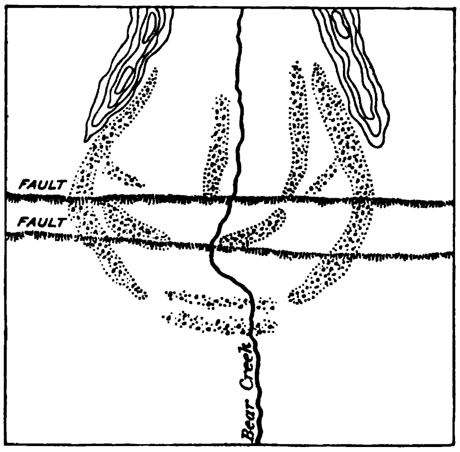


FIG. 12.—Sketch map of the morainic ridges near the mouth of Bear Creek canyon.

SOUTH DRY CREEK CANYON.

The valley of South Dry Creek canyon, extending from basin 31, is U-shaped, its form being just such as is commonly developed where there has been vigorous ice action, and, in proportion to its size, has a large catchment basin. The catchment basin is located on the northwest slope of Lone Peak, at an elevation of 10,000 feet. The ice that formed in this basin during the earlier glacial epoch descended more than 4,000 feet in about 3 miles and advanced nearly 1 mile beyond the mouth of the gorge. The outermost drift, which belongs to the earlier glacial epoch, was worked over by the waters of Lake Bonneville, buried by lacustrine and fluviatile deposits, and has since been uncovered locally by stream erosion. The evidence of the outer moraine consists of a belt of large white granite bowlders arranged in crescentic form opposite the mouth of the canyon. The position and condition of this outer morainic material indicates that it belongs to the earlier glacial epoch and that it was deposited before the last wide extension of Lake Bonneville.

Younger morainic ridges, 15 to 25 feet high, are lodged near the mouth of the canyon and extend a few rods into the Bonneville Basin. (See fig. 13.) These younger moraines are in part buried by fluviatile deposits and in part destroyed by erosion. White granite bowlders from the Lone Peak region are conspicuous in these moraines, but some limestones and sandstones, derived from lower portions of the canyon, are also found in them.

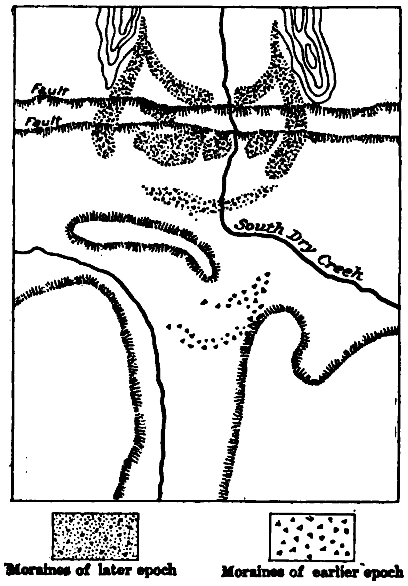


FIG. 13.—Sketch map of the morainic ridges near the mouth of South Dry Creek canyon.

Two fault scarps[a] that border the west base of the mountains cross the moraines of South Dry Creek canyon, causing distinct breaks of 15 to 30 feet in the crest lines of the drift ridges.

The other small canyons near Bear and South Dry creeks, on the west slope of the range, did not contain glaciers. They retain rugged V-shaped forms, developed by weathering and stream erosion, and at their mouths immense alluvial fans have accumulated since the recession of the Bonneville waters. These fans are beautifully symmetrical and some of them extend fully a quarter of a mile beyond the base of the mountains. The fan material is angular, containing blocks 2 and 3 feet in diameter.

BELL OR NORTH DRY CREEK CANYON.[b]

At the mouth of Bell, or, as it is sometimes known, North Dry Creek canyon, the first canyon south of Little Cottonwood, there is a series of symmetrical lobate moraines of magnificent proportions. (See fig. 14 and Pl. XI, *A*.) The ridges marked "L" in fig. 14 are sharp wedge-shaped forms extending almost a mile beyond the mouth of the canyon and rising nearly 500 feet above the highest Bonneville terraces and 700 feet above the stream bed at their western end. (See Pl. XIII, *A*.) Seven hundred feet is not, however, the maximum thickness of drift at the mouth of this canyon, for the base of the formation is not exposed. The crests of the main lateral moraines slope gently westward, indicating approximately the surface slope of the ancient glacier near its end. From aneroid readings the last three-quarters of a mile of the crest was found to have a slope of 190 feet. The portions marked "T" in fig. 14 may be considered terminal moraine hills which have been set off from the lateral moraines by fault scarps, as indicated in the drawing.

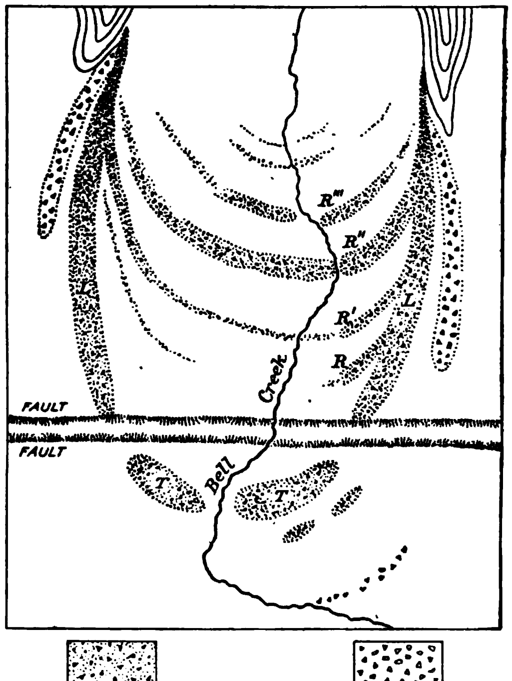


FIG. 14.—Sketch map of morainic ridges near the mouth of Bell Canyon.

Within the main moraines, and probably while the ice yet occupied the upper part of the valley, waters accumulated and formed a lake. The fault scarp that crosses the lake flat exposes laminated clays and cross-bedded sands and gravels to a thickness of several feet. The waters rose in this intermoraine basin until it reached the pass located near the middle of the terminal moraine. The lake was then drained by the outlet stream as it cut its gorge into the loose glacial material. The deposits made in this lake bury a part of the first reces-

[a] Gilbert, G. K., Lake Bonneville, Mon. U. S. Geol. Survey, vol. 1, pp. 346-348.

[b] In Mon. U. S. Geol. Survey, vol. 1, p. 309, Mr. Gilbert uses the name "Dry Cottonwood Canyon" for the one here reported as Bell Canyon, and calls one of the smaller glaciated canyons to the south 'Big Willow." The names here reported are those now in use among the residents.

A. CROSS SECTION OF SOUTH LATERAL MORAINE OF BELL CANYON.

Break caused by faulting and exposing characteristic glacial till. The freshness of the exposure in the central portion is due to recent excavations for an irrigation canal.

B. GLACIATED SURFACE OF CONGLOMERATE IN LITTLE COTTONWOOD CATCHMENT BASIN.

sional moraine (R in fig. 14) and leave but 5 or 6 feet of the second (R′ in fig. 14) rising above the lake flat. The third ridge (R″ in fig. 14) is the most prominent recessional moraine in the lower part of the valley, rising 20 to 25 feet above the surrounding land and maintaining a strong ridgelike form between the main lateral moraines. The fourth recessional moraine (R‴ in fig. 14) is represented by a belt of glacial bowlders rising 8 to 10 feet above its surroundings.

As the front of the glacier retreated the thickness of the ice in the valley became less, and at those stages when the minor frontal moraines that cross the valley were developed recessional lateral moraines were also made. These side moraines descend into the valley and, curving inward, join the recessional frontal moraines. This series of moraines is so well developed that the position and form of the lower portion of the glacier during successive stages of retreat are distinctly shown.

Outside the series of lobate or crescentic moraines there are considerable masses of drift which, from their appearance and condition, can not be classed with those just described. The surface material of these outer morainic masses is arkose, derived from the disintegration of white granites in the drift. Much of the larger material in the débris is so disintegrated that it may be crumbled between the fingers. A considerable exposure in a tunnel in one of these outer moraines showed that practically all of the abundant granite bowlders, some of them as much as 4 feet in diameter, had been so thoroughly disintegrated that they had been cut through with pick and shovel in the excavation of the tunnel. This condition was not superficial, but held to the depth of 20 feet, the deepest point of exposure.

Portions of the outer morainic material are buried under beds of sand and gravel associated with Lake Bonneville, as shown in fig. 15. Within a few yards of the exposure shown in fig. 15 there is a section showing a quantity of much weathered drift overlain by laminated clays. The conditions shown in these two exposures have an important bearing on the problem of correlating the glacial and Bonneville epochs.

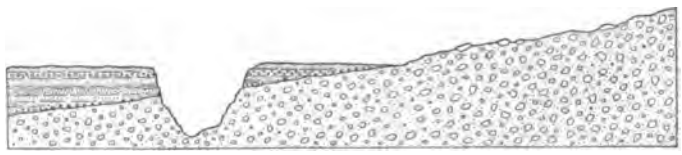


FIG. 15.—Stratified sands and gravels overlying till opposite the mouth of Bell Canyon.

The burial of the earlier drift by lacustrine sediments indicates clearly that they are at least pre-Bonneville in age. The disintegration of these older drift deposits is so much greater than the disintegration of the later deposits that the time which elapsed after they were deposited and before they were covered by the lake waters must have been many times longer than the time which has elapsed since the last retreat of the ice. In other words, the interglacial epoch must have been longer than the postglacial epoch.

Furthermore, the outer moraines above the Bonneville shore have suffered much erosion. They are softened in contour and somewhat dissected, whereas the inner moraines are fresh in topographic appearance as well as in the condition of their material. This evidence corroborates that found in Alpine Canyon, according with the fact determined at that place, that the ice of the earlier epoch was more extensive than that of the later.

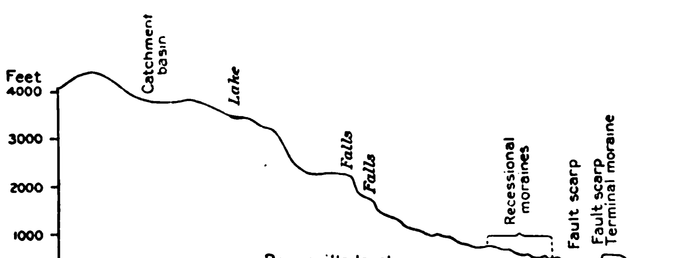


FIG. 16.—Profile of Bell Canyon from the catchment basin to the younger terminal moraine.

Above the moraines at the mouth of Bell Canyon the valley is a great rock gorge. The form of this gorge and the smoothed condition of its bare rock walls suggest at every step the amount and vigor of the work done by the ice that occupied the gorge and built up the moraines at its lower end. (See Pl. XI, *A*.) The trail upstream crosses great, irregular masses of drift. The ascent is by a series of gentle reaches and abrupt rock ledges. (See fig. 16.) Above each ledge the valley

bottom is somewhat level or rolling. Lakes or old lake beds are of frequent occurrence. The stream descends by rapids or falls from one bench or step in the canyon to the next below.

The entire fall from the catchment basin to the mouth is about 4,470 feet, an average of nearly 1,000 feet per mile. (See fig. 16.) This very high gradient accounts for the vigorous ice action recorded on the rock surfaces throughout the upper portion of the valley and in the massive moraines at and near the mouth.

The walls in the upper portion of the canyon are of white granite, and the immense amphitheatral catchment basin is hemmed in by granite peaks that rise to elevations between 11,000 and 12,000 feet. The upper limit of glaciation is clearly marked on the canyon walls at many places. The rugged, talus-clad summits present a sharp contrast to the smoothed and roche moutonnée surfaces below. The ice rose at many points within a few hundred feet of the top of the bounding walls. In the basin the upper limit of glaciation is not so well marked. Weathering and névé work in the higher altitudes has accomplished so much since the glaciers melted that the basin walls are rugged and heavily covered with talus. The general appearance in the basin suggests that, while the upper 1,000 feet of Lone Peak was probably not covered during the glacial epochs, most of the mountains rose but 500 or 600 feet above the snow fields.

Lone Peak and the surrounding peaks are among the first summits which the moisture-bearing winds from the west met, and as there were large catchment basins on all sides of them the heavy precipitation of the glacial period was retained, and vigorous glaciers developed from this center. The catchment basin of Bell Canyon is 2 miles long and about 1 mile wide.

If the region about Lone Peak could be pictured as it was during the ice age the view would be that of an immense snow field with rugged peaks rising above the white expanse, and six glaciers leading off in as many directions down the mountain valleys.

LITTLE COTTONWOOD CANYON AND ITS TRIBUTARIES.

The system of moraines at the mouth of Little Cottonwood Canyon is shown in fig. 17. The region included in the sketch map is complicated by the partial burial of some of the moraines; by postglacial erosion, which has uncovered some parts of the moraines and destroyed other parts; and by postglacial and post-Bonneville faulting. For these reasons it is not possible to trace every one of the frontal moraines from one side of the valley to the other.

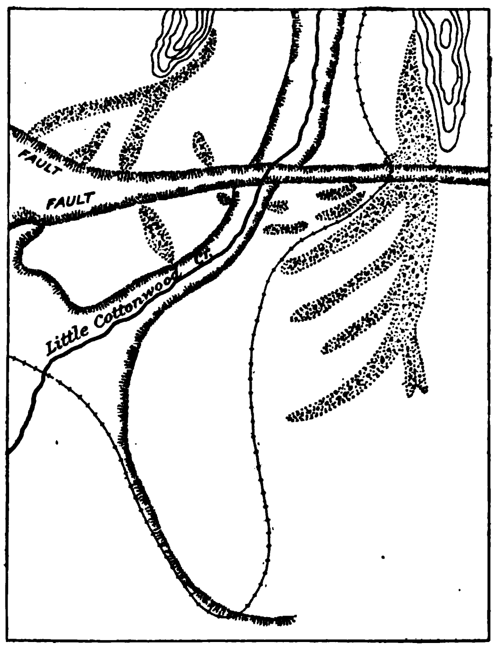


FIG. 17.—Sketch map of morainic ridges near the mouth of Little Cottonwood Canyon.

The postglacial and post-Bonneville faults indicated in figs. 12, 13, 14, 16, and 17 have been described by Gilbert.[a] These faults border the west base of the mountains, crossing the moraines of five of the glaciers that reached the Bonneville level. The offset or displacement varies with the different faults and from place to place in the same fault. Where the faults cross the moraines of Bell Canyon a westward-facing escarpment shows a displacement of over 100 feet (see Pl. XIII, *A*), while an eastward-facing escarpment indicates a displacement of about 15 feet. The distance between the two fault lines varies from 50 to 60 feet up to as many rods. At the mouth of Little Cottonwood Canyon a block has dropped in such a way as to form a troughlike depression, bordered on either side by precipitous faces. (See Pl. XIV, *B*.)

On the south side of the Little Cottonwood Valley, just west of the mountains, six distinct morainic ridges were recognized and mapped (fig. 17). On the north side of the valley but four well-developed ridges were determined. In the intervening area certain of the moraines are traceable by belts of large bowlders. The partially buried

[a] Lake Bonneville: Mon., U. S. Geol. Survey, vol. 1, pp. 346-348.

A. LITTLE COTTONWOOD CANYON.

Showing U-shaped valley.

B. VIEW NEAR MOUTH OF LITTLE COTTONWOOD CANYON.

Showing two postglacial fault scarps and an intervening depression.

moraines appear as ridges that contain many large bowlders, and rise from 5 to 10 feet above the fluviatile deposits about them.

The main south lateral moraine is a beautifully symmetrical ridge with a narrow crest, at places not more than 8 or 10 feet wide. The surface of this moraine, as well as the surfaces of all the Little Cottonwood moraines, is strewn with white granite bowlders (see Pl. XI, *A*) procured by the glacier in the lower part of its course. The crest of the main south lateral moraine rises 340 feet above the flood plain of the Little Cottonwood at the mouth of the canyon.

The north lateral moraine is not ridgelike, but is a great bank of drift lodged on the side of the mountain. The upper limit of the north lateral moraine material is at about the same elevation as the moraine crest south of the valley. The upper limit of the ice on this side is clearly shown by the upper limit of white granite bowlders on the mountain slope.

From fig. 17 and Pl. X, the notable northward turning of the Little Cottonwood glacier after leaving the canyon may be seen. This turning may have been due in part to a depression in that direction, but may perhaps be entirely accounted for by the greater westward extension of the south wall of the canyon as compared with the north. The north wall ends fully half a mile upstream from the terminus of the south wall, and the ice may thereby have been allowed to deploy to the northward.

Since the ice left the region, and since the lake waters retreated, Little Cottonwood Creek has cut a gorge 150 feet deep in the glacial and lacustrine material. The lowering of the base-level of the stream by the recession of the lake and the partial blocking of its waters by faulting have complicated the stream's history. The valley just west of the sunken fault block is a sharp V-shaped gorge, while above and below the faulting the valley is relatively broad and open.

The evidence of two ice advances down Little Cottonwood Canyon is fragmentary and inconclusive. Several patches of old, or at least distinctly weathered material were found at separated localities. At other points old-looking drift was found mixed up with very fresh drift. At no place was a distinct lower layer of old drift identified or an older outer moraine recognized. From the evidence found in other canyons, a part of which has already been given, it seems certain that the ice must have advanced down Little Cottonwood Canyon during at least two distinct epochs. The absence of conclusive local evidence is probably to be accounted for either by the fact that the ice of the last epoch advanced as far as the ice of any previous epoch, obliterating definite traces of the earlier advance, or by the fact that the older morainic remnants were buried under the Lake Bonneville beds. The Little Cottonwood glacier had exceptionally large and favorably situated catchment basins and a larger number of tributary glaciers than any other glacier in the region, and the later ice may have advanced in this valley as far as did the earlier.

Little Cottonwood Canyon has a beautifully symmetrical U-shaped form, characteristic of the vigorously glaciated canyons of the region. A good reproduction of the view up the canyon from the mouth is shown in Pl. XIV, *A*. The Archean rock near the mouth of the gorge weathers rapidly, and talus slopes are common. The white granite, which furnished an abundance of bowlders to the drift, forms the walls of the canyon for 6 or 7 miles upstream from the Archean outcrops. The surface of the granite has lost any striæ it may have had, but the great mass has weathered less than the Archean, and most of the valley slopes in this portion are smoothed to an elevation of 1,000 feet above the stream. This elevation represents, therefore, a minimum thickness of ice in this part of the valley. Here the slopes are too steep to hold any considerable body of drift, and too steep for ascent and close examination.

Pl. X shows the general arrangement of the moraines in the main and in the tributary valleys. Six of the seven valleys entering the main canyon from the south contained glaciers, which united with the ice in the main canyon. From the north there are few tributaries, and none that contained moving ice. The south tributaries are now hanging valleys, the streams in them having the characteristic falls and rapids in the lower portions of their courses. These falls or rapids begin at elevations between 200 and 300 feet above the main stream, and indicate by their position the approximate amount of ice gouging in the main canyon in excess of that in the tributary canyons. Striation and polishing are found in many of these tributaries just above the falls. In the second tributary below Alta, heading in basin 36, there are quartzite surfaces beautifully polished and striated. So smooth is the rock at places that the hand can detect no roughness. Vertical faces where ice plucking must have taken place are present,

causing the streams to descend by a series of steps. The tributary valleys which have been glaciated are all U-shaped. Lakes are common in them, and at their heads small snow fields are found even as late as August.

The catchment areas of these glaciated tributaries are large amphitheatral basins just north of the crest line between Little Cottonwood and American Fork canyons. The basins and the valleys below them are separated from one another by very narrow rock spurs, the crests of which are at places so narrow that travellers following such a divide find it necessary to go in single file. In these tributary valleys there are large quantities of drift, lodged as lateral moraines on the bounding slopes or as medial moraines that begin at the junction of branches or forks.

The coarse material of the drift at the mouth of Little Cottonwood Canyon is made up almost entirely of granite and Archean rock obtained by the ice in the last 7 or 8 miles of its course. One passing up the valley may note that the Archean first drops out and granite becomes the dominant material; then that Paleozoic rocks begin to appear, and as the granites become less numerous, that sedimentary rocks become more abundant. Very little material from the Paleozoic formations reaches the mouth of the canyon as coarse material. In general the amount of drift in the valley becomes less from the mouth of the canyon to the head. Two well-developed recessional moraines are located part way up the canyon, and there are occasional heavy deposits of drift on the valley slopes, but at the head of the valley, the path of the glacier has a cleaned-out appearance.

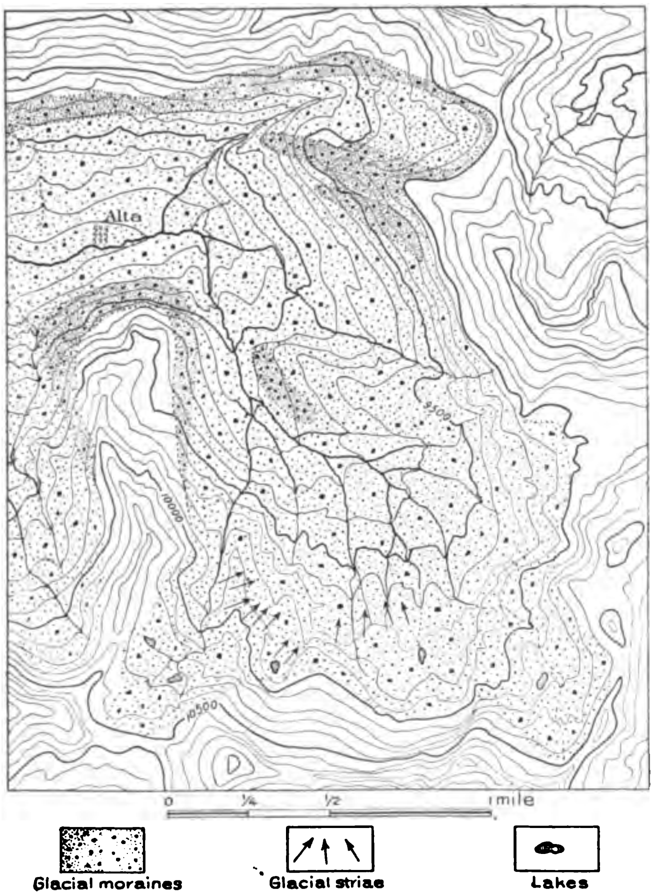


FIG. 18.—Sketch map of the catchment basin of Little Cottonwood Canyon, showing distribution of glacial drift and direction of striæ.

Near Alta, Cambrian, Silurian, and Devonian beds appear in the canyon walls, and, except where the beds are highly inclined, the topographic forms characterized by cliffs and talus slopes have begun to develop.

Not far above the first outcrops of the Paleozoic rocks the valley widens out into a great catchment basin (No. 38), bounded by beds ranging from the Cambrian to the Carboniferous, and containing in its central portion a large granite mass. This capacious basin (see fig. 18), from which the largest glacier of the Wasatch Mountains started, is about 2½ miles long and over 1 mile wide. In addition to the main area of snow accumulation there were three large tributary cirques. The snow field from which the Little Cottonwood glacier originated was fully 4 square miles in extent.

The lake in the main basin lies at the foot of the bounding cliff, in a rock basin 8 or 9 feet deep. Here, as at many other places among the mountains, the vigor of ice action at the very beginning of movement is illustrated. The rock around and beneath this lake is polished and striated.

In the catchment basin and on the bounding slopes the exposed rock surfaces also show the effects of most vigorous ice action. (See Pl. XIII, *B*.) The extent and completeness of the glacial scouring is astounding. Every conceivable thing that débris-laden ice might do

in passing over a rock surface is illustrated: Chatter marks, polished surfaces, deep grooves, knob and trail developments (see Pl. XIII, *B*), at points where the hard pebbles of a conglomerate protected the rock just beyond it from wear, rock basins, striæ on the under surfaces of overhanging ledges, curved striæ on a magnificent scale at places where the ice moved around some obstruction or over an inclined surface, and at one place six sets of striæ indicating as many directions of ice movement on a single surface.

A series of striæ shown in fig. 18, indicates the general direction of ice movement in the different parts of the basin. As a rule the movement was at right angles to the rim.

LITTLE WILLOW CANYON.

The glacier of Little Willow Canyon extended from the cirques (basins 39 and 40) west of Twin Peaks westward for a distance of a little more than 3 miles through Little Willow Canyon, and then beyond the mountains into the Bonneville Basin. (See fig. 19.) The postglacial part of the gorge is V-shaped, but if this lower portion be filled in, the cross section of the valley would have a symmetrical U-shaped form.

Lateral moraines cover the lower portions of the valley slopes, but do not stand out as symmetrical ridges, such as are seen about Bell and Little Cottonwood canyons. The morainic material is composed of quartzite, sandstone, limestone, gneisses, and schists, and much of it is subangular and striated. The terminal moraine has been largely carried away by erosion. At the western margin of the moraines associated with this canyon there is a westward-facing fault scarp 15 feet high.

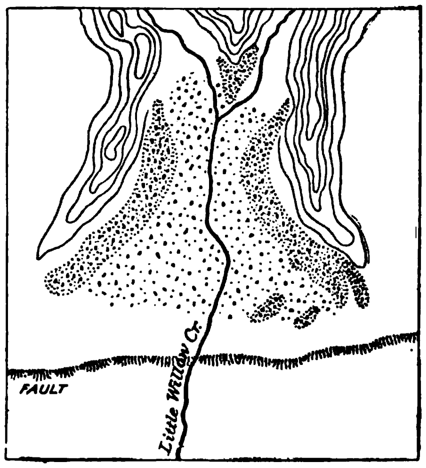


FIG. 19.—Sketch map of moraines near the mouth of Little Willow Canyon.

BIG COTTONWOOD CANYON AND ITS TRIBUTARIES.

As approached from the west, or the Bonneville Basin, Big Cottonwood Canyon does not appear to have been glaciated. Near the mouth of the gorge are two well-developed terraces associated with different levels at which the Bonneville waters stood (fig. 20). These terraces are made up of stratified sand, gravel, cobbles, and bowlders, the material growing coarser upstream. The surface of the upper terrace is 320 feet above the stream at the mouth of the canyon, its height being exactly the same on both sides of the stream and identical with the height of the Bonneville terrace, which is well developed on the west face of the mountains. This terrace continues to be well developed for a mile up the canyon, where its upper surface has been buried by alluvial fans. Farther up the valley, on the south side of the stream, its upper surface, banked against the west sides of a quartzite nose, appears again with great distinctness. According to barometric readings this upper surface is 20 feet higher than the Bonneville level 1½ miles downstream. The lower terrace is 110 feet below the Bonneville terrace at the mouth of the canyon, but it rises gradually until it grades into the upper terrace. This relation is shown in fig. 20.

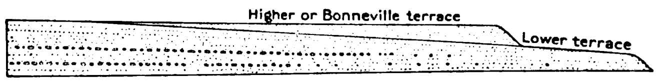


FIG. 20.—Diagram showing relations of terraces in the lower portion of Big Cottonwood Canyon.

During the maximum extension of Lake Bonneville a bay about 1½ miles long apparently extended up the lower end of Big Cottonwood Canyon. The slight rise in the surface of the alluvium is not too great a slope to carry delta deposits of material so heavy. The delta built in this bay was intrenched when the lake waters fell, so that a stream flat was developed. A second lowering of the lake caused the trenching of this stream flat, giving the second terrace. Still other terraces have been developed at lower levels.

In contrast to the smooth U-shaped form of Little Cottonwood Canyon, the Big Cottonwood gorge is rugged and somewhat V-shaped. Great cusps or points of rock project from the sides

of the gorge, and pinnacled, rugged faces stand out as indications that glacier ice never moved down the valley. The scarcity of weathered débris and a single deposit containing glaciated bowlders were the only things seen on the first ride up the canyon to raise a suspicion of former ice occupancy. Upon closer investigation, however, striæ, parallel to the trend of the valley, were found at four separate places. The location and direction of these striæ are shown on Pl. X. The rock ledges protruding into the valley near the upper power plant, about 4 miles above the mouth of the canyon, show by their striated, grooved, and polished surfaces unmistakable marks of ice action.

The evidence of glaciation in the lower part of Big Cottonwood is extremely scant, but its nature is such as to remove all doubt regarding glaciation. It is certain that a glacier once advanced down this canyon to the Bonneville shore line recorded in the bay-head delta above described.

The postglacial work in the lower part of this canyon indicates a much longer period of exposure than that which has elapsed since the Bell and Little Cottonwood glaciers last left their valleys. In fact the difference between this part of Big Cottonwood and any of the glaciated valleys heretofore described is so striking that but for the presence of indubitable striæ it would be hard to believe that the valley was ever occupied by ice. In comparison with the side canyon, Mill B, a tributary associated with basin 41, or with its own upper portion, the same contrasts are to be noted.

Big Cottonwood Canyon for several miles above the mouth of Mill B contains no traces of occupancy by a glacier, this portion of the gorge having an unmodified river erosion form.

At the mouth of Mill B and a few rods below there are strong, fresh moraines, which rise fully 150 feet above the Big Cottonwood stream. The lower slopes of the valley of Mill B are relatively smooth and nearly free from talus and other débris resulting from rock weathering, while the higher slopes are notably rougher and are covered with talus and disrupted and disintegrated rock. The junction of these two types of slope topography is held to mark the upper limit of the ice which moved down the valley, and it would indicate that the maximum thickness of the Mill B glacier was between 500 and 600 feet. The rock surfaces in the basin of Mill B (No. 41) are notably striated, grooved, and polished, and the postglacial work is insignificant.

In the amphitheatral basin the rock in the bottom is for the most part a hard quartzite, and yet there, at the very beginning of ice action, this hard rock was wonderfully and beautifully polished, grooved, and striated. The stoss sides of prominences are, almost without exception, so smoothed that it is difficult to walk over them if they have much slope. At one place the trail, wide enough for a horse to walk on, is located in a great glacial groove. Overhanging surfaces are polished and deeply striated. The general effect is that of a roche moutonnée area nearly as extensive as the floor of the catchment basin. Pl. XV, *B*, is a good representation of a small portion of this area.

Within the basin of Mill B there are three rock-basin lakes. These basins, having maximum depths of 20 feet, were gouged out by the ice. The downstream sides of the basins, where the ice moved uphill, are wonderfully grooved and striated. (See Pl. XV, *A*.) The catchment basin is large and well protected on the east, south, and west sides by lofty peaks.

The points of contrast between the valley of Mill B and the glaciated lower portion of Big Cottonwood, together with the fact that a portion of the main canyon above the mouth of Mill B is unglaciated, show clearly that the ice which passed through the lower portion of Big Cottonwood Canyon belonged to the earlier glacial epoch and represented the maximum extension of the Mill B glacier, while the more recent work throughout the length of the tributary valley belongs to the later glacial epoch. The relations also indicate that the time between the two was much greater than that since the last, so far as surface erosion can be depended on as a criterion.

A. ROCK-BASIN LAKE IN CATCHMENT AREA OF MILL B.
Showing glaciated surfaces on downstream side of lake.

B. GLACIATED SURFACES IN BASIN OF MILL B, A TRIBUTARY TO BIG COTTONWOOD CREEK.

The unglaciated portion of Big Cottonwood Canyon extends from Mill B to within a few rods of the mouth of Mill A, a distance of nearly 3 miles. The rugged walls with their heavy talus accumulations, the absence of smoothed surfaces, the general unmodified erosion forms, and the absence of drift in this part of the valley are sure indications that it was not glaciated.

Mineral Fork canyon, associated with basin 42, is the next tributary to Big Cottonwood east of Mill B. The dark rocks at the head of the basin have been smoothed and polished by the ice and the loose material has been carried down the valley. Striæ were observed on the basin walls 1,000 feet above the floor. About 1½ miles below the head of the basin there is a small morainic deposit in the midst of the valley, and about 2 miles from the head there are distinct lateral moraines. There are three morainic ridges on the east and one on the west. These ridges curve into the valley at their lower ends and mark the maximum position of the ice in this valley. Farther downstream there is a narrow rock gorge.

The ice of Mill A (basin 43) crowded down into the main valley of the Big Cottonwood and left a well-developed series of lateral, terminal, and recessional moraines. These moraines vary in height from 6 to 30 feet. The ice from the tributary met the ice in the main valley at its lower end. The terminal moraine of the main glacier is located opposite Mill A, but the ice from the tributary spread westward, so that a part reached the main valley fully a mile below the terminal moraine of the ice of the main valley.

The lateral moraine on the west, extending 1½ miles along the valley wall, is about 800 feet above the stream, indicating the very considerable thickness of the Mill A glacier. The moraine on the east side, though not well developed on the valley slope, extends one-half mile beyond the mouth of the canyon, curving down the main valley. Big Cottonwood Creek is located at the junction of the drift from the south with the mountain waste from the north. The tributary stream Mill A also seems to have been somewhat deflected by the glacial deposits, so that it now joins the main stream some distance below a point opposite the mouth of its canyon.

About three-fourths of a mile in front and a little to the west of the mouth of the Mill A gorge is a hill which rises almost 300 feet above the stream level at its northern base. This hill is covered with a thin layer of drift and is so located as to show clearly that it acted as a wedge, dividing the lower ice of the glacier which advanced on either side and finally encompassed this prominence. On the south side of the hill there are two distinct pairs of lateral recessional moraines. On the other sides of the hill there are also massive morainic deposits.

The canyon of Mill A is about 3 miles long, with mountains rising high on either side, and is U-shaped throughout its entire length. Its width at the mouth is nearly three-fourths of a mile. Drift is scarce on the sides of the canyon down to a point within a mile of the mouth, but on the bottom of the gorge there are great masses of drift, in which the stream is lost for a distance of a mile.

The catchment basin (No. 43) is bounded on the east, south, and west by high cliffs, which not only offer good protection to the snow falling there, but serve as a good trap for wind-blown snow. The basin is divided by a great rock ridge into two portions, the one on the west being the larger. Where the ice from these two portions of the basin met, a medial or inter-lobate moraine was formed, which is now lodged in the midst of the valley, in the lee of the separating ridge. At the head in the eastern portion of the catchment area there is a rock basin which has contained water. Masses of basalt near the center of this basin and along the side show distinct striations parallel to the direction of the canyon. In the basin there is about a square mile of nearly continuous rock surface which has been striated, chatter-marked, and grooved in a most striking manner. A rock ridge or mountain projecting into the valley from the southwest has been smoothed off by the ice 500 feet above the bed of the creek. Just below the catchment basin, where the valley widens, are four rock basins which were gouged out by the ice.

Up Big Cottonwood Canyon from the mouth of Mill A there are five other canyons coming from the south, from basins 44 to 48, inclusive, all of which contained glaciers that reached

the ice in the main valley. The ice in these several tributary valleys persisted longer than the ice in the main valley, and pushed through the lateral moraine of the main glacier, leaving at each side of the notch their own lateral ridges of drift. (See fig. 21.)

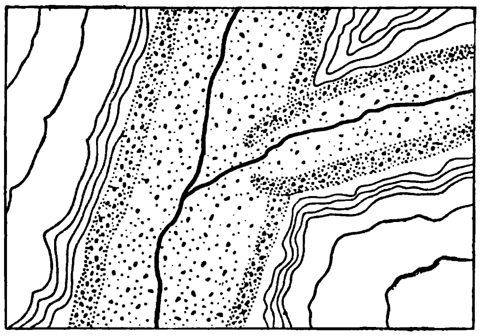


FIG. 21.—Sketch map showing arrangement of moraines where the lower end of a tributary glacier remained in the main valley after the retreat of the main valley glacier.

Most of these canyons are well cleaned out and U-shaped. At a few places enough drift has been lodged to cause local ponding of the streams. The arrangement of the moraines in and about these tributary valleys is indicated on Pl. X.

On the north side of the Big Cottonwood Canyon there are several tributary valleys, only one of which (basin 49) contained a glacier, and that failed to reach the main valley. The lower portions of the tributary canyons from the north were, however, occupied by ice, which moved up from the main valley, in some canyons, fully half a mile. Upstream from the ice in these tributary canyons alluvial flats were developed, partly by wash from the glacier, but largely by material brought by tributary streams. The morainic dams in these tributary gorges stand at elevations between 400 and 500 feet above the flood plain of the Big Cottonwood opposite the mouths of the tributaries. The position of these moraines indicates a thickness of ice in the main valley of somewhat more than 500 feet.

The general distribution of drift in the Big Cottonwood Valley is shown on Pl. X. The ice did not remain long at its position of maximum advance, for the terminal moraine is inconspicuous. On the valley slopes up to 500 feet above the stream there are successive lateral morainic benches. These moraines may represent stages in the melting of a single glacier, but differences in the thickness of soil and in the amount of disintegration on the moraines of the north slope indicate that the upper benches may belong to the earlier ice epoch. On the broad floor of the valley the drift at some places assumes a rolling topography, characteristic of the ground moraine in the North Central States.

At the head of Big Cottonwood Canyon is a capacious catchment basin (No. 50) with several tributary cirques. The serrated mountain peaks surrounding the basin rise from 1,000 to 1,500 feet above the area over which the ice moved, and their rugged, angular forms are set off sharply from the smooth and cleaned portion of the basin.

This basin is as large as any in the region, but is not so favorably situated for gathering snow as some of the other basins. A narrow crest separates the basins of Big and Little Cottonwood canyons, but the latter, being located on the windward side of this crest, received and retained a larger amount of snow than the former, or leeward, basin. The Little Cottonwood glacier was 12 miles long, while the length of the Big Cottonwood glacier was scarcely 6 miles. At one place in the rim separating basins 38 and 50 a band of ice connected the two great glaciers.

In the main basin of Big Cottonwood there is a swampy pond, surrounded by drift, known as Silver Lake. In one of the tributary cirques there are four rock-basin lakes, while Twin Lakes, located in another cirque, are also in rock basins.

The work of the Big Cottonwood glacier was largely erosional near the head and depositional lower down in its course. The ice did vigorous work near the starting points and weakened as it passed downstream, where the valley was wide and the gradient low.

MILL CREEK CANYON AND ITS TRIBUTARIES.

One entering Mill Creek canyon from the west, or Bonneville Basin, can see no signs of glaciation for 2 miles above the mouth of the gorge. At this point the valley of Mill Creek becomes wider and loses the rugged, pinnacled forms that are common farther below. In the wider portion of the valley there are remnants of till terraces rising about 90 feet above the

stream. These terrace remnants are in the form of benches left at intertributary spaces in the main valley. If the portions cut away by side wash and tributary streams could be replaced, the continuous lateral moraines once present in this part of the valley would be reproduced. The amount which has been cut away suggests a longer period of erosion than has elapsed since the final melting of the last glaciers of the region.

The lateral morainic remnants continue at intervals upstream to the junction of the two headwater streams known as the North and South forks, coming from basins 51 and 53. In the moraine remnants there is a great abundance of red sandstone, which points to the North Fork, and therefore to basin 51, as the source of the ice that moved down the main valley.

For a distance of 30 or 40 rods above the forking the South Fork shows no signs of occupancy by moving ice. In fact, the shape and general appearance of this part of the gorge, together with the absence of ice-brought material, exclude the hypothesis of ice action here. The South Fork has, however, been glaciated for 3 miles below its head. Four cirques, Nos. 53, 54, 55, and 56, in the high mountains of the divide between Mill Creek and the Big Cottonwood, supplied large quantities of snow and ice to this valley. The moraines in this fork are well developed and very fresh in appearance. They evidently belong to a different epoch from that which gave origin to those in the main canyon. Near the head of South Fork, in catchment basin 53, boggy lake flats are common.

Two miles above the lower limit of glaciation in Mill Creek canyon a tributary from basin 57 brought to the main canyon a glacier of considerable size. The deposits of this tributary glacier are too fresh to be correlated with those of the main Mill Creek glacier at the point of junction. Furthermore, the lateral moraines of this smaller glacier cut across the morainic terrace remnants of the main glacier in such a way as to indicate their later development. The relationship of the younger and older moraines at the mouth of this tributary is shown in fig. 22.

The suggestion best supported by the field data is that the main gorge was not occupied by the ice of the last epoch, but that the upper portions of the North and South forks and the entire length of the tributary from basin 57 contained ice during each epoch.

The ice in the main canyon was not very thick, perhaps not more than 200 to 300 feet for a considerable portion of its length, but, reinforced by the single tributary glacier, succeeded in reaching, during the earlier epoch, a length of 6 miles.

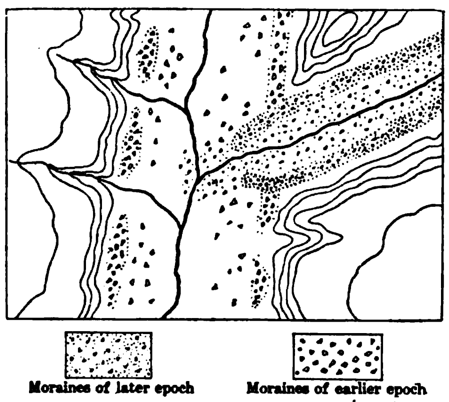


FIG. 22.—Sketch map showing arrangement of moraines where a glacier of the later epoch advanced into a canyon which had been occupied by ice only during the earlier epoch. Based on conditions in Mill Creek.

GLACIERS OF THE EAST SLOPE.

East of the crest line, in the region of greatest glaciation in the Wasatch Mountains, there were four glaciers, each more than 2 miles long. Two of these east-slope glaciers descended from the basins about Claytons Peak to the lowlands about Midway; the other two descended northeastward from the main crest line of the range to the vicinity of Park City.

Of those heading on the south and east of Claytons Peak, the one from basin 58 failed to reach the mouth of the canyon in which it moved. No conspicuous moraines were developed, and in general the ice action in this canyon was weak.

The other glacier descending toward Midway from basin 59 reached a maximum length of 5 miles, deploying on the lowland at the base of the range north of the little town of Midway. (See Pl. X.) In the capacious catchment area of this glacier there are now four small glacial lakes. Below the catchment basin large quantities of drift are lodged in the valley. Massive lateral and medial moraines are well developed throughout nearly the whole length of the gorge. A large part of the bowlders of the drift are crystalline, and near the mouth of the canyon an abundance of decomposed material is mixed with the fresher drift.

Of the two glaciers that descended to the vicinity of Park City one lay in the valley leading northeast of basins 60 and 61, and the other in the next valley to the west, locally known as Snyderville Valley.

The valley below basins 60 and 61 contains a heavy filling of talus, which at places covers the drift. In this valley thick soils have accumulated and dense forests, now partly removed, have clothed the slopes. This valley shows extensive postglacial erosion and in all ways presents an appearance indicating a very long period of exposure—much longer than that recorded in many of the glaciated valleys of the region.

The only suggestions of two epochs of ice advance are the fresher moraines in the catchment basin and the presence of a single lake. The ice of the last epoch may have occupied the basin, but failed to move down the valley.

SNYDERVILLE VALLEY.

Two large well-cleaned out basins, Nos. 62 and 63, separated by an unglaciated rock ridge, formed the catchment area of the Snyderville glacier. In the upper portion of the larger basin there are moraine-like ridges of fresh appearance, which may have been formed by ice of the later epoch. Thick soils have accumulated in both basins and dense pine forests cover the slopes.

In the south basin bare rock surfaces occur at only two places, and these are striated. Considerable angular mountain wash covers the drift in the basin. In the north basin is an old lake basin filled with alluvium.

From the basins two pairs of lateral moraines extend downstream. At several places talus has accumulated over these moraines. The lower ends of both pairs of moraines have been largely cut away by erosion, bowlder ridges alone remaining to mark their former positions.

The amount of soil accumulated in the catchment basins and their forested condition, the filled lake basin, the amount of fine wash over the drift and rock in the catchment basin, the talus slopes over the moraines in the valley, the amount of erosion since the ice left, and the faintly striated condition of the bowlders of the drift, all favor the hypothesis that the Snyderville glacier belonged to the earlier ice epoch and that small snow or névé fields existed in the basins during the later epoch.

THE FARMINGTON REGION.

About 18 miles north of Salt Lake City, east of the little village of Farmington, the crest of the Wasatch Mountains runs near the western border of the range and reaches an elevation of 10,000 feet. On the east side of this lofty crest snows accumulated which gave rise to a glacier that first moved northward, and then, by a right-angled turn, came, by way of Farmington Canyon, through the main range of the mountains, reaching a point within 2 miles of the mouth of the canyon. (See Pl. X.) The traces of glaciation in the lower part of the glacier course are scant, having been largely destroyed by postglacial erosion. The ice of the last epoch may have been restricted to the upper part of the gorge. The west face of the range east of Farmington was not glaciated.

NÉVÉ FIELDS.

Within the area studied about twelve névé fields have been located. These accumulations of snow, many of which probably comprised a little ice, were subject to some movement. The material moved is all angular, and at places is arranged in irregular ridges inclosing areas that now contain lakes. The basins of such névé fields do not show such scouring or cleaning as do the glacier basins, nor are the erosion lines in them so completely erased.

It would be impossible at this day to determine just which of the basins not mapped as glaciated contained névé fields without glacier ice and which contained some small amount of ice with névé. Only where positive proof of ice action was found are glaciers indicated on the map.

SUMMARY AND CONCLUSIONS.

DISTRIBUTION OF GLACIERS.

Within the area studied the positions of fifty Pleistocene glaciers exceeding a mile in length were determined. (See Pl. X.) Many of the smaller glaciers were tributary to the larger glaciers of the range. Traces of several glaciers less than a mile in length and of more than a dozen névé fields were also found and mapped. Of the fifty larger glaciers, seven reached the shore line of Lake Bonneville, and the moraines of at least three of them are partially buried by fluviatile deposits near the shore, possibly by the shore deposits of the lake itself.

The valleys of the west slope are much longer than those of the east, and the glaciers of the two slopes were, in a general way, of corresponding lengths. The number of ice tongues on the west was much greater than on the east. Of the fifty glaciers over 1 mile in length, forty-six were west of the crest, and but four east of it. Of the ten glaciers that reached or exceeded 5 miles in length, nine moved westward and but one eastward. The Little Cottonwood glacier, on the west slope, was 12 miles long, while the greatest length reached by any glacier on the east slope was 5 miles. East of the crest one glacier descended to an altitude as low as 6,000 feet, and two descended to 7,000 feet. On the west slope fourteen glaciers descended to an altitude of less than 6,000 feet, and seven to 5,000 feet.

The greater number and size of the glaciers on the west side of the range, as compared with the east side, were determined by larger catchment basins and heavier snowfall. A third factor of local importance was the accumulation of snow in catchment basins among the lofty peaks of the two east-west divides lying west of the main crest. Many of these basins furnished tributary glaciers to the main canyons, and thus greatly increased the amount and strength of the work done by the ice on the west side of the range.

Glaciation was not only more extensive but also more vigorous on the west side of the range than on the east. This is shown by a more complete cleaning out of loose material from the glaciated valleys of the west slope; by the more complete reduction of their asperities of surface; by the greater deepening of the main canyons on this side, leaving their tributary valleys "hanging" 200 to 300 feet above the main valley bottom; and by the development of more massive moraines. The moraines of the east-slope glaciers are insignificant in comparison with those of the west-slope glaciers.

The elevation of a catchment basin necessary to give rise to a glacier in this region was between 8,000 and 9,000 feet, and, except where the basins were very favorably situated, the latter figure is more nearly correct.

TOPOGRAPHIC EFFECTS OF GLACIATION.

Most of the valleys that were occupied by ice are U-shaped, and their slopes are commonly smoothed off as far up the sides as the ice reached. Such forms are in sharp contrast with the V-shaped canyons and rugged slopes of the valleys not occupied by ice. (See Pl. XII, *A*.) In several of the glaciated valleys massive moraines were built up. Some of these moraines are in the canyons and some at their mouths, their positions according with that reached by the ends of the glaciers at the time of their maximum extension. Where tributary glaciers joined the main glacier medial moraines were formed, which now stand as ridges in the midst of the valley. Many recessional moraines cross the valleys as crescentic ridges, convex downstream. Some of these ridges served as dams, above which lakes accumulated (see fig. 23),

FIG 23.—Diagram of a lake retained by a morainic dam.

rose, and overflowed. The outlet streams of such lakes cut gorges in the moraines. Near the heads of many valleys the ice gouged out rock basins (see fig. 24) 50 to 200 feet in diameter and 5 to 20 feet in depth. At least thirteen of the thirty-six glacial lakes mapped are in rock basins apparently made by the ice.

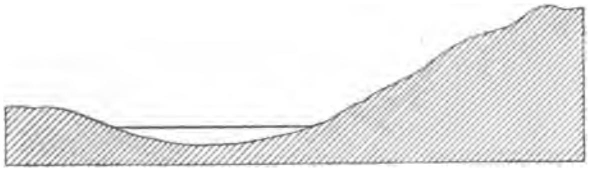


FIG. 24.—Diagram of a lake in a rock basin.

DISTINCT GLACIAL EPOCHS.

The work here reported removes all doubt as to the duality of the ice age in the Wasatch Mountains. Other investigators of the Utah-Nevada region have concluded that the two periods of humidity recorded in the lacustrine beds should be correlated with distinct glacial epochs. King[a] writes: "The first long-continued period of humidity is probably to be directly correlated with the earliest and greatest glacier period, and the second period of humidity with the later Reindeer Glacier period." Gilbert, at the close of the chapters on the history of the Bonneville Basin, writes:[b] "It follows as a corollary that the glacial history of this region was bipartite, two maxima of glaciation being separated not by a mere variation in intensity, but by a cessation of glaciation." It is certain that there were at least two ice epochs separated by a long interglacial interval. Evidence of more than two epochs was not found. The basis for the above conclusion is as follows:

1. In several valleys there are outer moraines much older than the inner moraines of the same valleys.

2. In certain glaciated canyons the variations in the amount of postglacial change (weathering, erosion, etc.) which different portions of the drift and valley walls have suffered are so great that it seems necessary to postulate much longer exposure for certain parts than for others. In all such places the drift which appears to be older extends beyond that which appears to be younger. The ice of the earlier epoch was therefore more extensive than the ice of the later epoch.

3. The drift buried under Lake Bonneville sediments is much older than that resting upon these sediments.

4. Certain glaciated canyons have been free from ice very much longer than those that were certainly occupied by ice during the later epoch. Such canyons were presumably glaciated during an earlier epoch and not during the later.

CORRELATION OF THE BONNEVILLE AND GLACIAL EPOCHS.

The relation of the moraines at the west base of the Wasatch to the fluviatile (or shore) deposits in the Bonneville Basin indicates, as Gilbert has pointed out, that the last advance of the ice from the mountains occurred during a late period in the history of Lake Bonneville. Mr. Gilbert says:[c]

> If the glaciers had attained their maximum extent either during or before the epoch of the Bonneville shore line, their terminal moraines would have been subject to wave action at that horizon and scored with shore marks, but the two terminal moraines, which are well exposed to view, exhibit no shore lines. If the glaciers had attained their maximum after the close of the Provo epoch the Little Cottonwood moraines should rest upon the alluvium, instead of being partially buried beneath it. It appears quite consistent with the phenomena to suppose that the epoch of maximum glaciation was covered by the longer epoch of the Provo shore line. The greater part of the alluvium outside the moraines may have been deposited while they were in process of formation, the intermorainal portion being added after the ice had retreated.

The close correlation of the earlier ice epoch with the earlier wide extension of the Bonneville waters can not yet be asserted, but the once deeply buried drift opposite the mouths of Alpine, South Dry Creek, and Bell canyons would indicate that there were moraines in the region before the last advance of the lake waters.

[a] U. S. Geol. Explor. 40th Par., vol. 1, p. 524. [b] Mon. U. S. Geol. Survey, vol. 1, p. 318. [c] Mon. U. S. Geol. Survey, vol. 1, p. 310.

It is interesting to note here another conclusion of Gilbert's, that "the inter-Bonneville epoch of low water was of greater duration than the time that has elapsed since the final desiccation."[a] The glacial evidence already given in detail indicates that the interglacial period was of much greater duration than the time that has elapsed since the final melting of the glaciers.

POSTGLACIAL CHANGES.

Since the ice last left the region the weathering and erosion have been trivial. The morainic material of the last epoch is but little disintegrated, and most of the streams are yet engaged in clearing away the glacial débris from their courses. Since the ice melted changes in temperature, frost, and moving névé have so combined as to produce greater effects near the summits than elsewhere.

[a] Mon. U. S. Geol. Survey, vol. I, p. 316.

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